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# Life cycle cost: an examination of its application in the United States, and potential for use in the Australian Defense Forces

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# NAVAL POSTGRADUATE SCHOOL

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# THESIS

## LIFE CYCLE COST: AN EXAMINATION OF ITS APPLICATION IN THE UNITED STATES, AND POTENTIAL FOR USE IN THE AUSTRALIAN DEFENSE FORCES

by

John D. Clarke

June, 1990

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This research has two objectives: firstly, to examine the application of life cycle costing in the United States; and secondly, to discuss its potential for use in the decision making of the Australian Defense Forces. It has been found that despite almost 30 years of application in the United States, life cycle cost, for the most part, is given little real attention in decision making. Reasons for this include: an institutional emphasis that accords greater attention to acquisition cost than life cycle cost; and the dominance of a budgeteers view of life cycle cost as a technique for affordability analysis, an approach which the current state of the data does not readily support. Life cycle cost's greatest potential is as a criteria to evaluate and tradeoff design and logistics issues, but it receives comparatively little emphasis in these areas. For Australia to avoid the problems experienced in the U.S., there needs to be acceptance at all levels of the concept of life cycle cost, and what it is trying to achieve.

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# Life Cycle Cost: An Examination Of Its Application In The United States, And Potential For Use In The Australian Defense Forces.

by

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# ABSTRACT

This research has two objectives: firstly, to examine the application of life cycle costing in the United States; and secondly, to discuss its potential for use in the decision making of the Australian Defense Forces. It has been found that despite almost 30 years of application in the United States, life cycle cost for the most part, is given little real attention in decision making. Reasons for this include: an institutional emphasis that accords greater attention to acquisition cost than life cycle cost; and the dominance of a budgeteers view of life cycle cost as a technique for affordability analysis, an approach which the current state of the data does not readily support. Life cycle cost's greatest potential is as a criteria to evaluate and tradeoff design and logistics issues, but it receives comparatively little emphasis in the U.S. in these areas. For Australia to avoid the problems experienced in the U.S., there needs to be acceptance at all levels of the concept of life cycle cost, and what it is trying to achieve. Since the cornerstone of the techniques of life cycle cost analysis is the data, an accounting system capable of capturing direct and indirect costs is needed. This study contains seven broad points for Australia to consider in implementing the techniques and concept of life cycle cost.

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# I. INTRODUCTION

On 24 May 1989 the Chief of the Australian Defense Forces, General P.C. Gration directed that:

> procedures [be instituted ] which will allow consideration of appropriate Life Cycle Costs in the decision making process associated with the acquisition of equipments and weapon systems. [Ref. 1]

Up to this point the major considerations in the acquisition decisions of the Australian Defense Forces had been the trade off of performance considerations with acquisition cost.

## A. THE CONCEPT OF LIFE CYCLE COST AS A DECISION TOOL

What differentiates Life Cycle Cost (LCC) as a decision making tool is its consideration of the total costs of ownership of a system over its life cycle. Thus it is a womb to tomb concept which includes the consideration of:

- **Research and development (R&D) cost**—The cost of feasibility studies; system analyses; detail design and development, fabrication, assembly, and test of engineering models; initial system test and evaluation; and associated documentation.
- **Production and construction cost**—the cost of fabrication, assembly, and test of operational systems (production models); operation and maintenance of the production capability; and associated initial logistic support requirements (e.g., test and support equipment development, spare/repair parts provisioning, technical data development, training, entry of items into the inventory, facility construction, etc. )
- **Operation and maintenance cost**—the cost of sustaining operation, personnel and maintenance support, spare/repair parts and related inventories, test and support equipment maintenance, transportation and handling, facilities, modifications and technical data changes, and so on.

- System retirement and phase out cost—the cost of phasing the system out of the inventory due to obsolescence or wear out, and subsequent equipment item recycling and reclamation as appropriate. [Ref. 2:p. 19]

Having defined life cycle cost in this way however, the costs of retirement and phaseout are rarely considered unless disposal is known to be particularly expensive as, for example, it might be with a nuclear power plant. Thus, the prime differential between the life cycle cost and traditional costing approaches is its consideration of operation and support costs.

Typically the costs of operation and support over a systems life cycle outweigh its acquisition cost, and account for 50 to 75 percent of total life cycle cost. This has become increasingly so even as the unit acquisition cost of military hardware has risen. In fact, higher unit costs have resulted in even higher operating and support costs as systems have become increasingly complex and less reliable [Ref. 3]. With a finite defense dollar available one consequence of this is to decrease the funds available for other uses. As a decision making tool therefore, life cycle cost analysis is concerned with the future consequences of present day decisions on the use of scarce resources [Ref. 4]. It is intended to allow decisions to make better use of these resources.

The breadth of the decisions for which life cycle costing can be used is succinctly summarized by Earles:

> Life cycle costing is a costing discipline, a procurement technique, an acquisition consideration and a tradeoff tool. As a costing discipline it is primarily concerned with operating and support (O&S) cost-estimating methods. As a procurement technique it is concerned with minimizing total life costs for component procurements. As an acquisition consideration its primary concerns are source selection and the balancing of acquisition and ownership costs. As a tradeoff tool its primary concerns are repair levels and the impact of specific design features on operating and support costs. [Ref. 5:p. 5]

Thus, life cycle cost is not only an analytical method that can be used to quantify and tradeoff costs, it is also a concept that aims to influence decisions to be favorable to reducing the total costs over a systems life cycle.

## B. COMPLEMENTARY CONCEPTS TO LIFE CYCLE COST

### 1. Life Cycle Cost and Design to Cost

Complementary to life cycle cost is the concept of design to cost. Both are management strategies aimed at ensuring affordable weapon systems are acquired by the military services. In design to cost, design parameters and cost goals are imposed on design. The cost can be acquisition or life cycle cost. When it is life cycle cost, parameters for operating and support costs as well as sailaway or flyaway cost are included. Although life cycle costing and design to life cycle cost are complementary, they are not the same. As was will be discussed in Chapter II, life cycle cost is one side of the cost versus effectiveness tradeoff of cost effectiveness analysis. Design to cost on the other hand, is not concerned with the optimal life cycle cost effective solution, because the design for such a solution may be above the affordable cost ceiling [Ref. 6:p. 4].

### 2. Life Cycle Cost and Integrated Logistic Support

Integrated logistic support is defined by the U.S. Department of Defense Directive 5000.39, *Acquisition and Management of Integrated Logistic Support for Systems and Equipment,* as being:

> A disciplined, unified and iterative approach to management and technical activities necessary to:
>
> a. Integrate support considerations into system and equipment design.

b. Develop support requirements that are related consistently to readiness objectives, to design, and to each other.

c. Acquire the required support.

d. Provide the required support during the operational phase at minimum cost. [Ref. 7:p. 2-2]

As a discipline, ILS is concerned with many of the same issues as life cycle cost. It attempts to influence design and acquisition decisions in terms of supportability, and provide a support infrastructure that achieves the required balance between cost and effectiveness. One way to view the relationship between ILS and life cycle cost is that life cycle cost provides a readily understandable quantifiable measure of the effect of logistics concerns. From this view, life cycle cost can be seen as an aspect of ILS.

### C. Categories of Cost

In discussions of cost, cost is often categorized in to three broad groupings. These are either:

- **Recuring and Non-Recuring Costs.** Non-recuring costs are those that are only incured once, or infrequently at irregular periods within a specified time frame. The costs of research and development (R&D) and production, are non recuring costs in the lifecycle of a system, as are the costs of providing the initial ILS to a program. Recuring costs are those that occur regularly and frequently. The costs of operating and support are recuring costs.
- **Fixed, Variable and Semi-Variable Costs.** Fixed costs, at least in the short term, are unchanged with the level of activity. Variable costs on the other hand, exhibit a direct relationship with the level of activity. To these, a hybrid category of cost called semi-variable costs must also be added. Semi-variable costs change with the level of activity but not in direct response to those changes. Most fixed costs if viewed over a long enough time frame are actually semi-variable costs. In the operating and support costs, variable costs, for example, include the costs of fuel, depot maintenance, and spare parts. Fixed costs include base and facilities operations, and many administrative functions. However, over time

these can be varied with the level of activity, and are therefore, also semi-variable costs.

- **Direct and Indirect Cost.** Direct costs are those that are traceable to an activity. Indirect costs are shared costs and can not be directly attributed to any one activity. This division is largely for reasons of practicality. All costs should be traceable, however it is often not convenient to do so. The term overhead is commonly used to group all indirect costs. In accounting practice, rules are developed to allocate overhead in a consistent and reasonable way to activities.

There is considerable overlap in the categories of cost, direct costs for example, can be both fixed and variable, and fixed costs can be recurring costs. These terms will appear throughout this study.

## D. PURPOSE OF THIS STUDY

If the Australian Defense Forces are to use life cycle costing as a decision making tool, a thorough understanding of the techniques and process is required. The United States (U.S.) Department of Defense have have been using life cycle costing for over 30 years, and much can be gained for Australia in examining the ways it has been implemented in the U.S. However, life cycle costing is not without its problems or critics in the U.S. This thesis will examine the ways life cycle costing has been applied in the United States, what the fundamental characteristics of a process that uses life cycle costing are, and what problems and criticisms there are with its application. Having learnt from the U.S. experience, it is intended to apply this experience to discuss some broad issues with the implementation of life cycle costing into the decision making of the Australian Defense Forces. Thus, the purpose of this study is two fold: to examine and reach conclusions on life cycle costing in the U.S., and to apply these conclusions to issues with the implementation of life cycle cost analysis to Australia.

## E. RESEARCH QUESTIONS

In concert with the purpose for this study, the primary research question with which It will be concerned is: what are the essential issues to consider in the application of life cycle costing to the decision making of the Australian Defense Forces? In the course of answering this question the following subsidiary research questions will also be addressed:

- What are the principle characteristics of a life cycle cost analysis approach to decision making?
- How and with what success is life cycle costing used in the U.S. Department of Defense, and what criticisms are there of it?

## F. RESEARCH METHODOLOGY

The methodology used in this study consists of an extensive review of current literature including texts, journal articles, theses, reports and Service directives. In addition, personal interviews were held with people involved in life cycle costing, its conduct and management in the U.S. The interviews focused on people in three areas: those involved in the Navy and at the Office of the Secretary of Defense in preparing and reviewing life cycle cost estimates, personnel in current USN programs—the SSN 21 SEAWOLF submarine and CG 47 AEGIS ship, and with contractors who have had extensive experience in life cycle costing. The emphasis is on the U.S. Navy because it is the Navy with which this author is most familiar, and additionally, because in the literature it is the Navy which is least represented, particularly in the application of life cycle costing to ships and ship systems.

## G. SCOPE AND LIMITATIONS OF THE STUDY

This study is primarily concerned with the *process* of life cycle costing as it applies to major weapon systems acquisition, the way life cycle cost analysis is used, and the problems and limitations of its use. It will consider the application of life cycle costing to all aspects of major weapons system acquisition. Its intended to discuss the principles of life cycle costing by way of introduction and understanding, rather than as a detailed examination of the methodology. However, where methodology is a problem these limitations will be examined in detail.

## H. ORGANIZATION OF THE THESIS

This study is divided into three chapters in addition to this general introduction and a conclusion. Chapter II is a discussion of the process of life cycle cost analysis. This chapter will provide a general analysis approach as a framework to discuss some of the broad issues in life cycle costing and introduce the reader to the concepts and techniques of life cycle cost analysis. In Chapter III the regulations and organizations in the U.S. responsible for life cycle cost will be examined and conclusions reached on the approach taken to life cycle costing in the U.S. Also, in chapter III some of the issues, limitations and problems encountered in the practice of life cycle cost will be examined. To complement this chapter, an appendix with two brief case studies: the SSN21 SEAWOLF submarine, and the F/A 18 HORNET aircraft will be used to illustrate the different approaches to life cycle costing. The conclusions reached from the examination of life cycle cost in the U.S. in Chapter III and the appendix will be applied as lessons learnt in Chapter IV, to discuss some of the issues with the application of life cycle costing into the decision making of the Australian Defense Forces. Chapters II, and III will provide answers to the subsidiary research questions of this study, and Chapter IV will answer the primary research question that has been posed.

# II. THE PROCESS OF LIFE CYCLE COST ANALYSIS

This chapter will provide an overview and context for the concept of life cycle cost as a decision making tool. The relevance of the points brought out in this chapter will be enlarged upon in the following chapter where the current state of life cycle costing in the U.S. Department of Defense will be examined. This chapter can be thought of as the theory, and the following chapter the practice of life cycle cost. This chapter will examine life cycle cost generically, looking at its principles of application. It will deal with the essential factors influencing an equipment's life cycle cost, and the methodology and models for measuring cost. To illustrate the principles of life cycle cost analysis, it will be discussed in the context of a general analysis approach. This approach is represented diagrammatically at Figure 1, and will provide a framework for examining the major requirements and issues of life cycle cost analysis. The discussion of this chapter is keyed to the *flow* of the analysis at Figure 1. Life cycle cost analysis is an iterative process. Once an initial analysis had been done, it is likely that all or parts of the process will be revisited and revised, and the objectives of the analysis reviewed. This is the significance of the returning arrow in the figure.

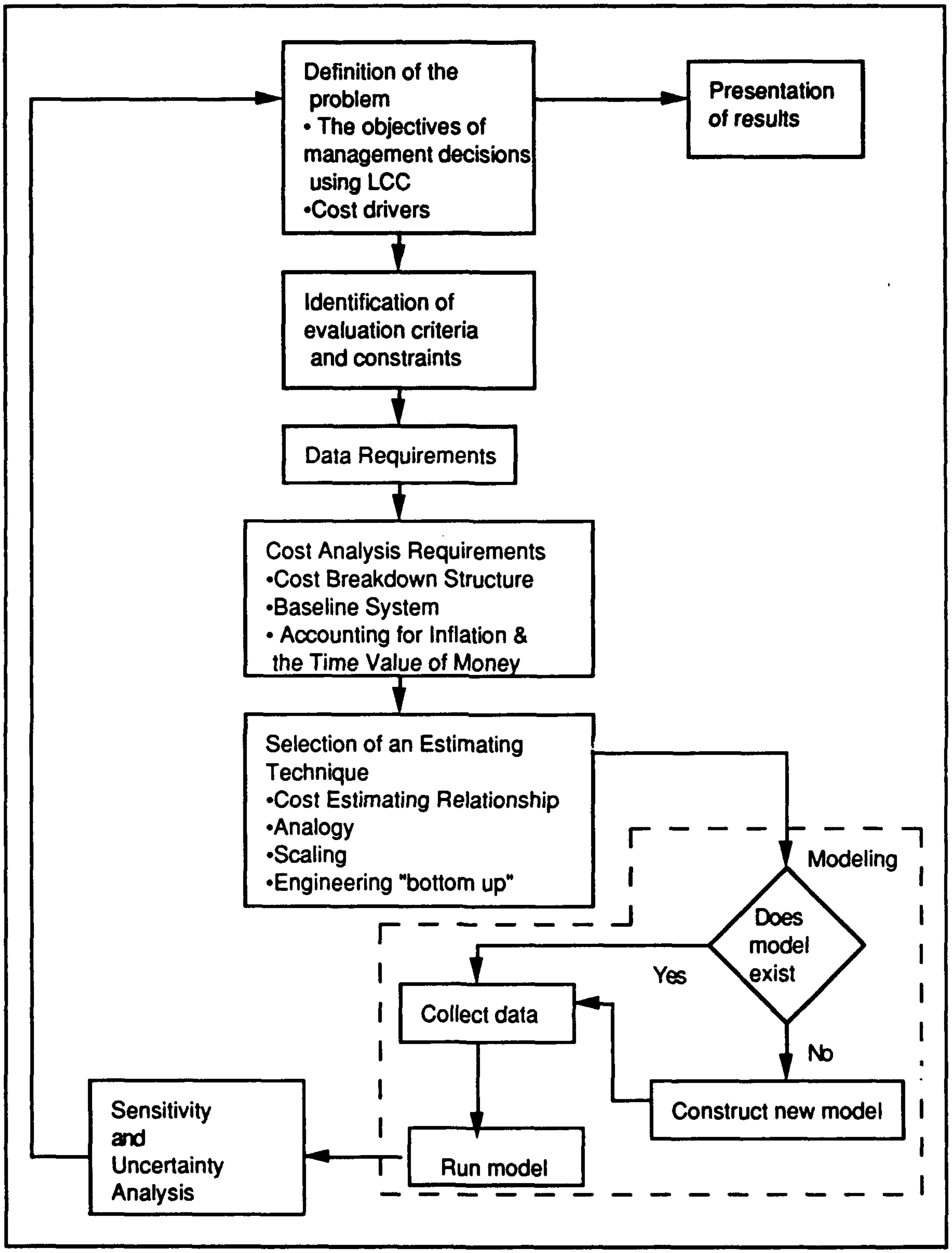


Figure 1. Life Cycle Cost Analysis Process

## A. DEFINITION OF THE PROBLEM

### 1. The Objectives of Management Decisions Using Life Cycle Cost Analysis.

The introductory chapter to this study defined life cycle cost as a decision making tool that is concerned with the future consequences of present day decisions. A life cycle cost approach therefore, can be applied to almost any decision that will have an effect on resource use in the future. In its application to decisions concerning weapons system acquisition, life cycle cost's four principal uses are:

- **Affordability Analysis.** To determine which approach, amongst a range of alternatives, provides the required capability to meet a mission need at least overall cost, and whether this cost is affordable in terms of expected future budgetary flows.
- **Detailed Design.** To determine the optimal level of reliability, maintainability and supportability of the design. (These terms will be defined and discussed in the next section) Such decisions concern the balance of the costs of automation, accessibility and quality of components with their life cycle cost savings.
- **Source Selection and Evaluation.** When there are competing designs for meeting a mission need, such as in procurement of developed commercial systems, each design is analyzed in terms of its life cycle costs. The process and criteria for evaluating the life cycle costs of different developed designs in source selection are the same as when using life cycle cost in detailed design. If life cycle cost is used in detailed design, the designer is trying to incorporate in the design the life cycle cost priorities of the customer. If used by the customer for source selection, the customer is quantifying the effects of the designer's decisions, and selecting the the system which best meets their life cycle cost and effectiveness priorities.
- **Logistics Support Decision Making.** While logistics support decisions will have to accord with the design selected, decisions concerning maintenance policy, facilities, support equipment and spares should be made based on their impact on life cycle costs.

The different decisions for which life cycle cost analysis is used are just different points along the same continuum. An analysis may start for affordability, but over time be modified and refined to become the basis for an analysis of logistic support decisions. However, the exact purpose for which an analysis is to be used needs to be defined and understood because, as will be discused latter, the requirements for the different types of analysis can be different.

### 2. The O&S Cost Drivers—Factors That Influence Life Cycle Costs

Efforts to reduce cost in the future are concerned with identifying the characteristics of a system that influence costs, and making tradeoffs early that will result in future cost savings. The future cost savings which the techniques of life cycle cost analysis are, for the most part concerned, are savings in operation and support costs. The major costs in operating and support are usually fuel, manpower, depot rework and spares. The system characteristics that influence these and other elements of cost are called cost drivers. In the analysis process the cost drivers need to be identified and their effects emphasized.

Efforts at reducing operation and support costs usually center on increasing a system's reliability and maintainability; where reliability is the probability that an equipment will fail, and maintainability is the ease and accuracy with which maintenance functions can be performed. Reliability and maintainability are the most significant cost drivers because they have wide ranging impact on the elements of operating and support cost. The reliability of a system determines the number of corrective maintenance actions, and maintainability the time required to repair it when it fails. These factors determine at what maintenance level—operational, intermediate or depot the failed component should be repaired, or if instead of being repaired, whether it should be discarded. In turn, these decisions will effect the number and skills of maintenance personnel, the quantity and disposition of spares and support equipment, and the technical data required.

The impact of these factors on cost should not be understated. It was Milton Freedman that said there is no such thing as a free lunch in economics, and the same can be said of life cycle cost. Both reliability and maintainability are characteristics of the design. While designing for these characteristics may cost very little, it might also cost a great deal. The methodology of life cycle cost is concerned with the trade-off of the impact of designing for increased reliability and maintainability on operating and support costs, against any additional R&D and production cost that might be incurred. There comes a point when the marginal cost of improved reliability and maintainability exceeds the marginal benefit in reduced operating and support costs. This is illustrated in Figures 2 and 3 for the ARC-164 aircraft communication system. In Figure 2 the projected reliability of the equipment is plotted against the increasing estimated acquisition cost to obtain it, and separately against the reduced estimates for operating and support costs it will yield. The two resulting curves are summed to obtain the life cycle cost curve. It can be seen that a point is reached at around a Mean Time Between Failure (MTBF) of 1000 hours where the life cycle costs begin to rise.

The thrust of efforts to minimize life cycle cost is therefore directed at finding the appropriate balance of minimal maintenance cost and acquisition cost. But, reduced maintenance cost means not only improving the MTBF, it requires at the same time making the equipment less expensive to fix when it fails. Modularization, built in test equipment, provision of test points, and ease of access, are all design characteristics of maintainability which impact on the cost of repair.

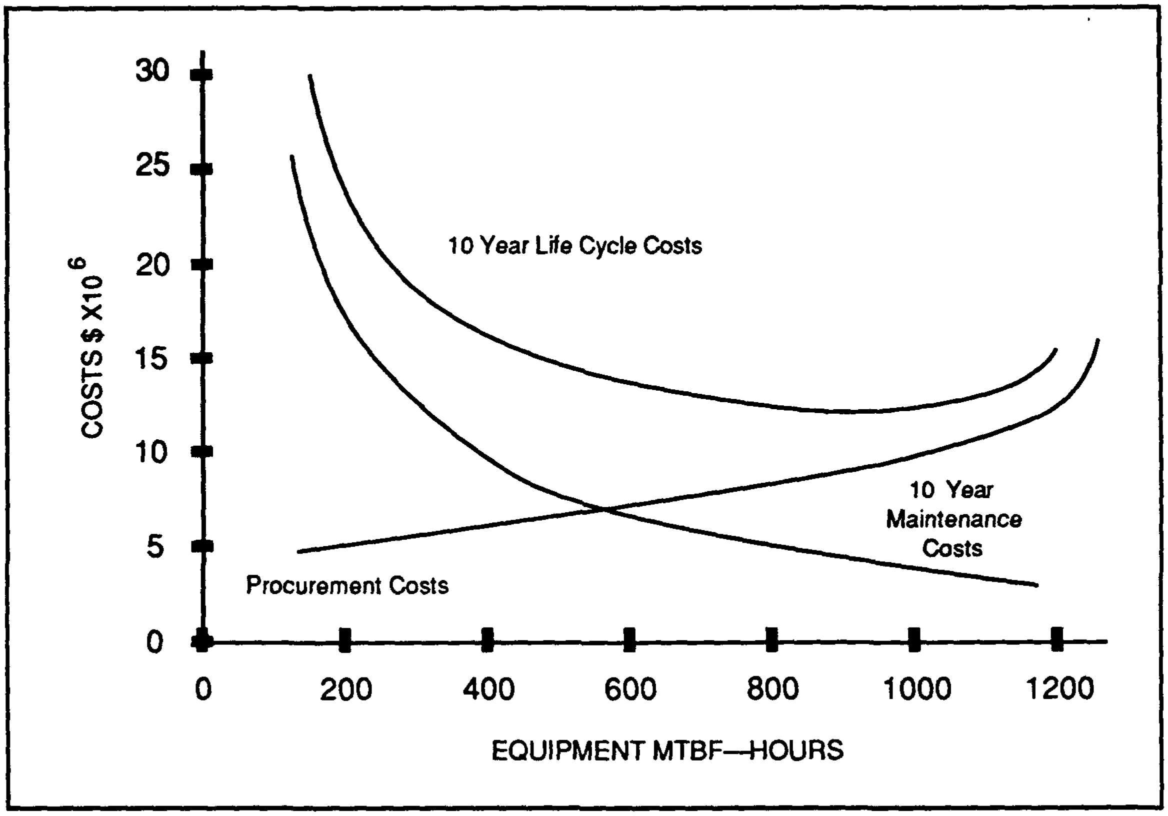


Figure 2. Relationship of Procurement Costs, Life Cycle (10 year) Maintenance Costs, and Life Cycle Cost to Equipment MTBF for the ARC-164 [Ref. 8:p. 15]

Another of the cost drivers is the supportability of the equipment. Supportability is the degree to which the system can be supported both in terms of its inherent characteristics of design and the effectiveness of the overall support capability of the client military services. [Ref. 2:p. 16] Major considerations in supportability include commonality of parts with those already in the inventory, the capability of the system to be tested without extensive special purpose test equipment, nor the need to establish special facilities for its repair. Systems that are able to utilize much of the existing infrastructure result in considerably reduced initial acquisition logistics costs, require smaller inventory levels of spare parts, and can have significantly reduced training costs.

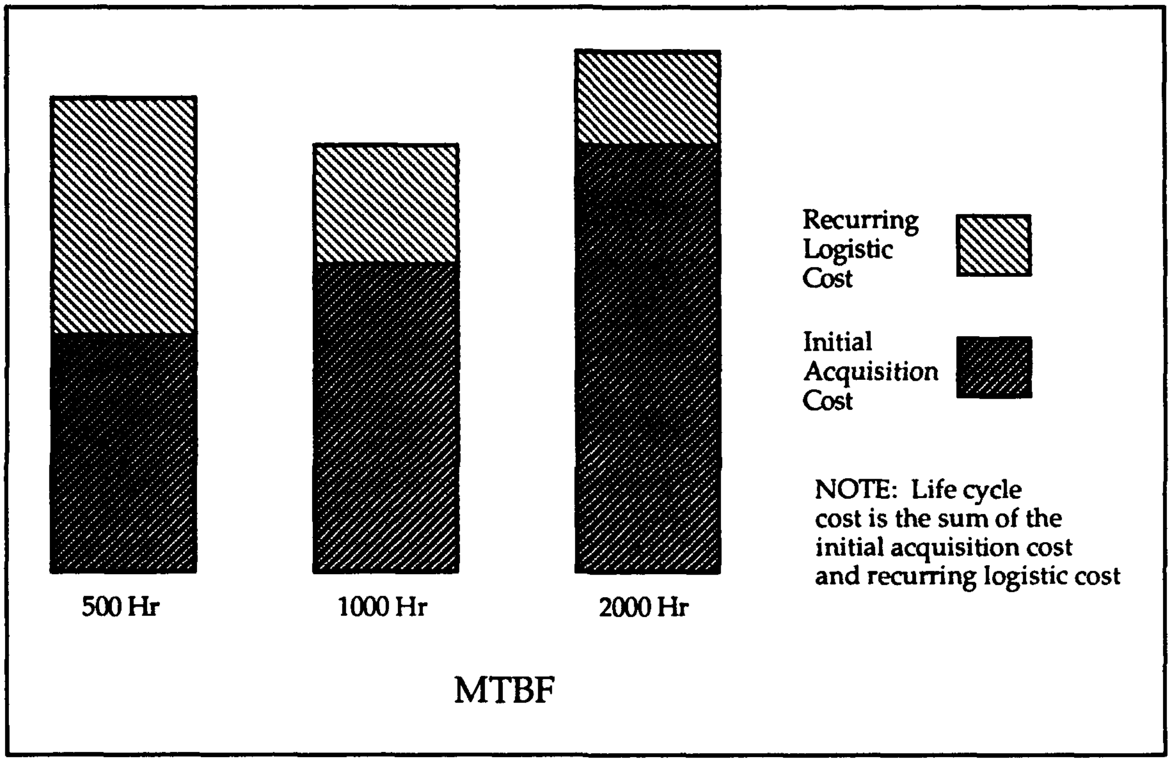


**Figure 3. Life Cycle Cost Versus MTBF for the ARC-164 [Ref. 9:p. 32]**

Therefore, as a decision making tool, life cycle cost is concerned with the trade-offs of the effects of the cost drivers. Many of the cost drivers are a reflection on the design of the equipment. These are critical relationships and should be understood and identified early in the decision making process.

## B. EVALUATION CRITERIA AND CONSTRAINTS.

### 1. Evaluation Criteria

Decisions concerning the life cycle cost of a system do not occur in isolation. They must be balanced against issues of effectiveness. Effectiveness is "a measure of the extent to which a system may be expected to achieve a set of specified mission requirements, and is a function of availability, dependability and capability." [Ref. 10] Thus, life cycle cost analysis is really one aspect of a more general cost effectiveness analysis. This relationship between life cycle cost and system effectiveness is represented diagrammatically at Figure 4. The criteria for effectiveness are factors such as physical system parameters like size, weight or capacity; and performance parameters such as range, probability of kill, and availability. There are many ways to tradeoff effectiveness. Two examples will be given.

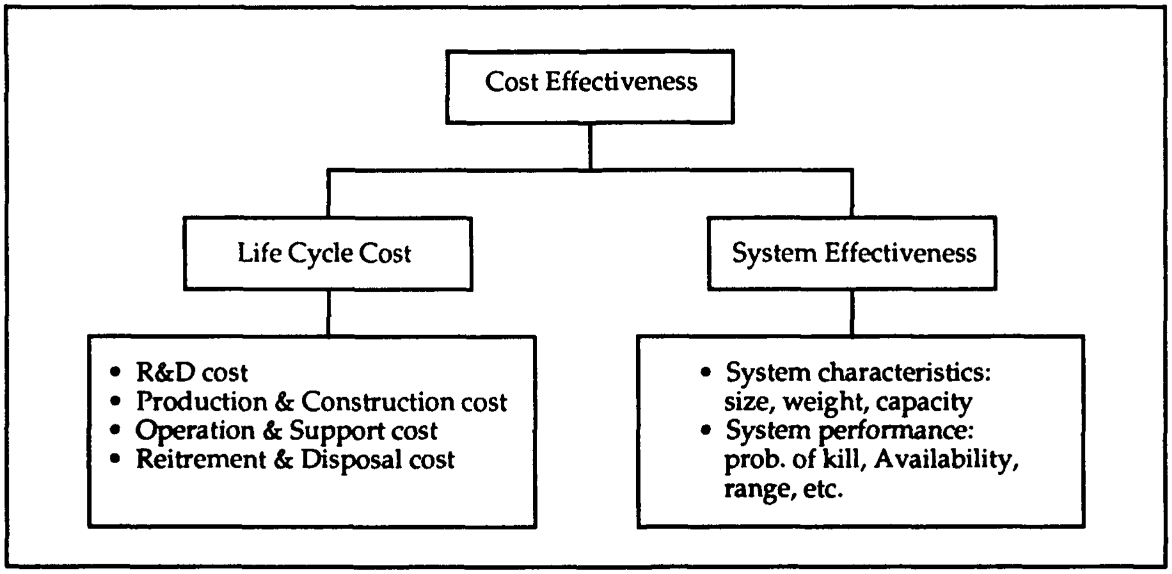


**Figure 4. Cost Effectiveness [Ref. 11:p. 12]**

Firstly, using the availability of a system as a measure of effectiveness. Availability is defined as a measure of system readiness that "determines the degree, percent, or probability that a system will be ready or available when required for use." [Ref. 2:p. 64] There are three different measures of availability: inherent, achieved, and operational. Operational availability is the most widely used and will be discussed here. Mathematically operational availability (Ao) is expressed as:

$$A_o = \frac{\text{MTBM}}{\text{MTBM} + \text{MDT}}$$

where MTBM, the mean time between maintenance, includes the time between both preventative and corrective maintenance; and MDT, the mean down time, includes the time to perform the maintenance and any logistics or administrative delay time. The operational availability of a system is effected by its reliability, maintainability, and supportability. As can be seen by examining the mathematical representation of Ao, if the MTBM can be increased, by say making the system more reliable, (that is, increasing its MTBF) the operational availability will also be increased. Similarly, if the system can be repaired quickly because it has built-in test equipment, modular components to facilitate removal, and uses standard components so that there is a greater probability of a spare being in stock when required, then the MDT will decrease, and the operational availability increase.

A second example of effectiveness tradeoffs might be the probability of mission completion. The effects of reliability (MTBF) on this measure of effectiveness will be illustrated. If to complete its mission a system is required to be operational for 400 hours, and it has an MTBF of 250 hours, there is only a 20 percent chance of mission completion. (Probability of mission completion = $e^{-n\pi t}$ where n = number of units, $\pi$ = failure rate, and t = time.) If the MTBF can be increased to 750 hours, the probability of mission completion still only increases to 58 percent. The MTBF has to be increased to around 4000 hours before the probability of mission completion exceeds even 90 percent. However, if instead of one system there are two, and it is only necessary for one of the systems to be operational to complete the mission, if the MTBF is 250 hours there is a 36 percent chance of mission completion. If the MTBF is increased to 750 hours there is a 82 percent chance, and if it is increased to 4000 hours there is a 99 percent chance of mission completion. This logic applies whether the question is to build in redundancy, that is parallel systems, or to determine an optimal number of units in a fleet in order to complete a mission. A similar effect can be shown if instead of increasing the MTBF the number of hours of service required from the system (t) is reduced in increments.

In conducting effectiveness tradeoffs the question needs to be asked whether the increases in effectiveness are justified in relation to their cost impact. In many instances, such as in the examples above, measures of effectiveness can be increased by impacting the operation and support cost drivers, such that there is a resultant increase in effectiveness and decrease in operating and support costs. But this might not always be so, and may be outweighed by increased acquisition cost. In the case above, where adding another system of the same reliability increased effectiveness, it would likely increase acquisition cost, and may also increase operation and support costs because of the requirement to operate and maintain twice as many systems.

The difficulty in determining cost effectiveness is to meaningfully compare the value of different levels of effectiveness. In the illustration at Figure 5 for example, in Case 1, choice A is clearly preferable to choice B because it has both lower life cycle cost and higher effectiveness. However, in Case 2, A is only preferable to B if the value or worth of the increase in cost is offset by the increase in effectiveness.

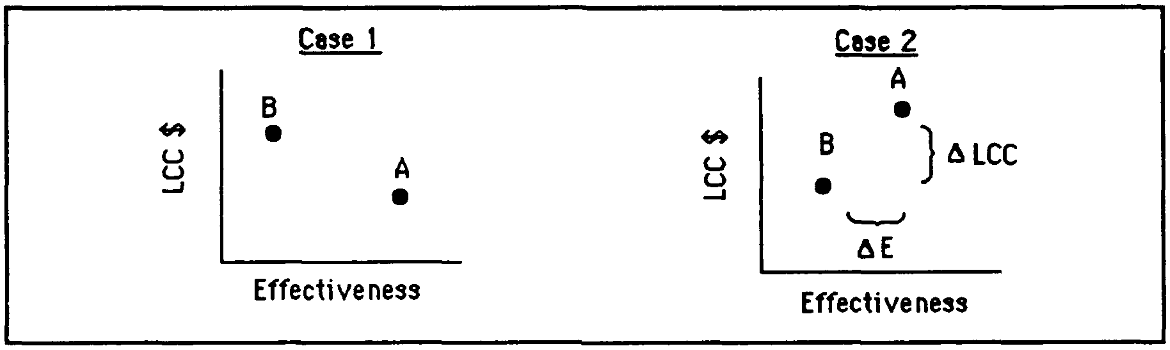


**Figure 5. Life Cycle Cost Versus Effectiveness Tradeoffs [Ref.12:p. 2-6]**

Since the purpose of life cycle cost analysis is rarely to determine the life cycle cost per se, but to compare and trade it off against some other criteria, these criteria need to be defined in the analysis process, and there needs to be some understanding of the relative weight of effectiveness and cost.

### 2. Constraints

All decision making is subject to certain constraints. These may be imposed by the design of the equipment, operational constraints on minimum performance criteria that the system must meet, or constraints as simple as the time frame in which the analysis must occur. All constraints serve to limit the analysis and restrict the options of the decision maker. For example, it may be a requirement that a system be overhauled in the field by operational personnel regardless of whether it is the most cost effective maintenance policy. Similarly, for operational reasons, a minimum reliability threshold of 2000 hours MTBF may be imposed on a system even though to do so results in a higher life cycle cost than if a lower MTBF had been specified. If design to cost goals and thresholds are imposed on a program these will be constraints to which the analysis should be oriented.

A further set of constraints, not usually considered, are the implicit characteristics of the user's internal environment. These are factors such as the skill levels and rank structure of operators and maintainers, the administrative lead time to process demands for spares and push defective items through the repair pipeline, the inventory holding cost for spares, basing policy, and the overhead of administrative activities. In an illuminating article *I Dreamed We Went Nowhere in Our Solid Gold Airplane*, the President of Boeing Aerospace, O.C. Boileau [Ref. 13], identified this operating and support cost *overhead* as the largest single encumbrance to realizing significant life cycle cost savings in defense. These implicit constraints are factors which the decision maker inherits, and over which in the short term he has little control. Constraints are a limiting factor in the analysis, and along with the evaluation criteria need to be identified in the analysis process.

## C. DATA REQUIREMENTS FOR ANALYSIS

### 1. Data Requirements and Availability.

Data is probably the single most important and most difficult part of the analysis process. Life cycle cost analysis is based on the assumption that past experience is an accurate guide to the future. Therefore, in order to predict the future, something needs to be known of the past. Three types of historical data are required for cost analysis:

- **Resource data.** Which includes such things as the time to manufacture or repair an item, the skill levels and costs of the personnel involved, and the material used in the manufacture or repair.
- **Physical and Performance Characteristics.** These include not only factors like weight, range and power, but MTBF, mean time to repair (MTTR), and measures of the support environment.
- **Program Data.** Which includes the delivery schedule, planned utilization, basing and deployment, and the maintenance concept. [Ref. 14]

The availability and accuracy of data is likely to be a major limiting factor in the analysis. The data required will depend on the accuracy and detail of the decision at hand, and the cost estimating technique to be used. Usually the engineering type of data should be fairly readily available even if only as estimates in the initial analysis, but ironically resource and physical and performance data concerning the users own environment is likely to be the most suspect. This is partly because cost data needs to reflect not only direct costs, but a sound allocation of all indirect costs. There is great difficulty in this allocation, and it is one of the major stumbling blocks to the credibility of the analysis. One method to obtaining this data is input-output analysis.

### 2. Input-Output Analysis: The Navy Resource Model (NARM)

Input-output analysis is a technique used for determining indirect costs associated with a decision. Where this is particularly useful is in determining the indirect costs associated with operation and support that may not otherwise be visible or difficult to allocate. For example, if a new system requires additional training of operators and maintainers, the workload on the training establishments will be increased, which in turn, will mean the training establishment will demand more from the other support resources. [Ref. 15:p. 5] To model this situation and capture indirect cost using input-output analysis, the U.S. Navy developed the Navy Resource Model (NARM).

Input-output analysis examines the interrelations between components of a system by accounting for the flow of resources. It does this by firstly dividing the system up into sectors, and then the sectors into two groups: those that produce goods and services, which are support sectors, and those that only consume output, which are called final users. [Ref. 16:p. 4] In the NARM the sectors represent organizations or functions such as Anti-Submarine Warfare and Recruit Training. [Ref. 15:p. 5] Since the output of one sector becomes an input to another, the problem becomes one of modeling the changes in the level of activity of the final users with changes in the workload and resources consumed by the support sectors.

Rather than attempt to measure the actual output provided to users by the support sections, input-output analysis uses proxies for real output. These proxy variables are characteristics of the system that are assumed to vary roughly in proportion to the real measure. In the NARM, for simplicity, the proxies are either operating costs or manpower.[Ref. 15:p. 5] To organize the data, it is assembled into a transaction matrix where each row represents the output of that sector, and shows how this is allocated to each of the consuming sectors. The basic format for the transaction matrix is illustrated in Table 1, and a numeric example in Table 2.

Table 2 illustrates that, in this particular example, to support the command sections output of 8557 units, it requires 456 units of operation and maintenance (O&M) and 328 units of manpower. If this were a life cycle cost analysis, where the impact of two alternatives were being examined, the changes caused by each alternative could be assessed and quantified for addition in the analysis.

TABLE 1. INPUT-OUTPUT TRANSACTION MATRIX [Ref. 17]

| | SUPPORT | END USER | TOTAL |
|---|---|---|---|
| **SUPPORT** | Support of Support | Support of End User | Total Support |
| **RESOURCES** | Resources for Support | Resources for End user | Total Resources |

TABLE 2. TRANSACTION MATRIX NUMERIC EXAMPLE [Ref. 15:p. 5]

| | Command | Training | TacAir | ASW | TOTAL |
|---|---|---|---|---|---|
| **Command** | 815 | 1542 | 2920 | 3280 | 8557 |
| **Training** | 328 | 864 | 406 | 665 | 2263 |
| **O&M $** | 456 | 259 | 286 | 367 | |
| **Manpower** | 328 | 864 | 406 | 665 | |

Use of the NARM is not as widespread as it used to be, although it is still in occasional use. It was for example, used for the SSN-21 operating and support cost estimates discussed as a case in the appendix. The problem with it is that its proxy variables are crude, and do not necessarily reflect the true propotion of the relationship between components of the system. Input-output analysis none-the-less remains a valid approach to the difficult task of determining the indirect costs associated with decision alternatives.

### 3. Data Issues in Life Cycle Cost Analysis

For the purpose of life cycle cost analysis however, it is by no means agreed how important it is to have data that accurately reflects all costs. There are two views to this issue. On the one hand it is argued that life cycle cost is not conducted for the purpose of finding out the life cycle cost per se; it is done as a means of comparison and tradeoff with the life cycle cost of other systems, and for evaluation against other criteria. In this case what is important is that the same costs are applied to each system, and that the costs are reasonable, if not accurate. In such comparisons there will be costs between systems that are common and can be ignored. This, for example, is the reasoning of Life Support Cost models (to be discussed latter in this chapter) for considering only the direct support costs of alternatives. Central to this view is that even if costs were known and accurate, there are so many other sources of uncertainty in the analysis that emphasis should be on visibility and simplicity. Taken to its logical conclusion, this view argues that, early in the life cycle when life cycle cost analysis is mostly applied, there is little real data on the system under examination. Because the data used is historical from another system, which may bear only some resemblance to the system being analysed, capturing the right data is of little consequence [Ref. 18].

On the other hand, if real and accurate costs are not known the real relatives between alternatives will not be known, and this may inhibit the decision. The consequences of not knowing the real relatives between alternatives will be discussed latter in this chapter in the context of risk and uncertainty. Additionally, for affordability decisions one of the criteria against which a proposal will be judged is anticipated future budgets. If accurate data is not available this sort of decision can not occur. A further problem with a lack of accuracy is that it reduces the credibility of the analysis undertaken.

There is no totally correct answer to this debate. Ideally, accurate historical data would be available with which to conduct the analysis. While historical costs of other systems may not exactly reflect the future costs of the system under examination, it is the only means to estimate these costs, and a better estimate will be obtained with accurate historical data than without. However, there are many instances when the decision to be made does not require analysis of all the life cycle costs. Such a decision might, for example, be when conducting level of repair analysis or even some design tradeoffs, when only a certain aspects of a system's cost need be examined over the life cycle. Still however, if the data that is needed is accurate, better decisions are likely to result.

## D. OTHER COST ANALYSIS REQUIREMENTS

### 1. Cost Breakdown Structure

In order to identify all the elements of relevant cost for life cycle cost analysis in a consistent and logical manner, a cost breakdown structure (also known as a cost element structure) is developed. The cost breakdown structure is a hierarchical division of cost by function and major element. It is very similar to a Work Breakdown Structure (WBS), and is usually based on this. The lowest hierarchical level to which the cost breakdown structure will descend will depend on the estimating technique to be used and the nature of the decision for which the analysis is being conducted.

### 2. Baseline Systems

A common and valuable technique in cost analysis is baselining. This involves comparing the known costs and cost drivers of a baseline system with those of the system subject to analysis. The baseline system is both a reference point for the cost analyst and for the decision maker to help identify relevant costs and cost drivers, to act as a check of the analysis, and to aid in focusing in on problems of the past which a new design may alleviate. Needless to say, the baseline system should be as close to possible in its physical and performance characteristics with the system under analysis. In acquisition decisions the reference system is usually the old capability which it is proposed to replace.

### 3. Accounting For Inflation, and The Time Value of Money.

Because of the modern ravages of inflation, any analysis that uses cost as a unit of measurement must ensure that it is expressed in a consistent common year basis. Inflationary indices should be applied to all historical cost data to ensure that they have a common base year.

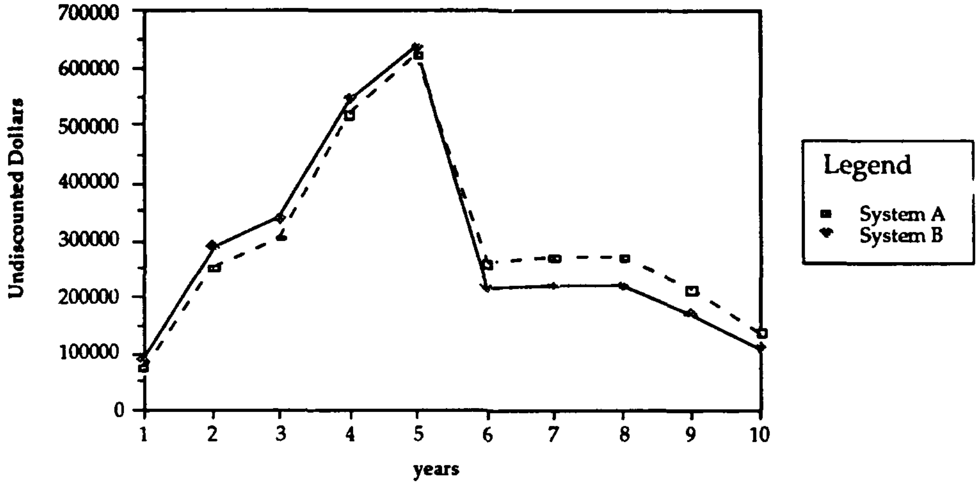
When considering costs to be incured in the future, consideration should also be made of the time value of money. That is, that money invested in the near term has more value than money invested in the distant future. This is because there is an opportunity cost of money. If money is invested now, its use for other productive purposes is precluded. To account for the time value of money the technique of discounting future cash flows is used. Its effect is to make alternatives that require spending sooner less attractive than those that defer spending to some future date. This is illustrated in Figure 6, where on the basis of undiscounted life cycle cost the

### SYSTEM A

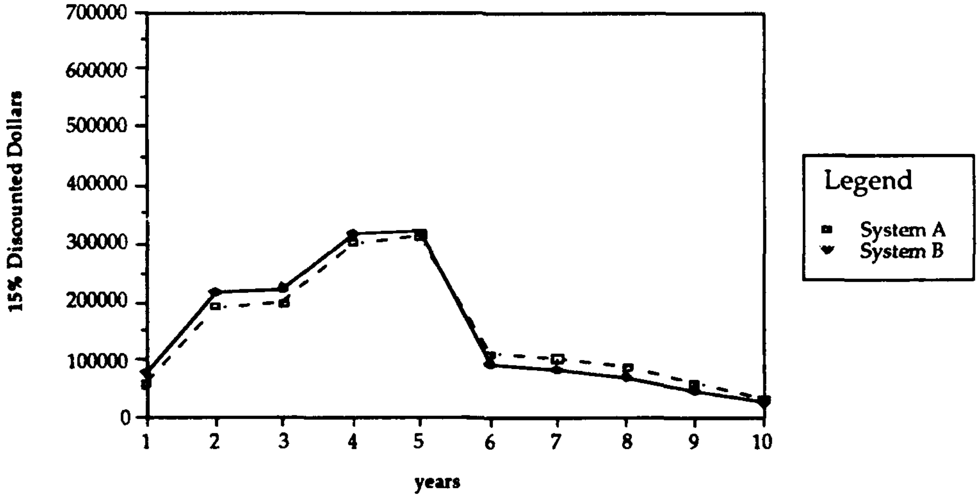
| YEAR | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Totals |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Year Total | 70000 | 250000 | 300450 | 521349 | 622698 | 258497 | 269396 | 269396 | 211027 | 134698 | 2907511 |
| Discount Fact | 0.870 | 0.756 | 0.658 | 0.572 | 0.497 | 0.432 | 0.376 | 0.327 | 0.284 | 0.247 | |
| N.P.V | 60900 | 189000 | 197696 | 298212 | 309481 | 111671 | 101293 | 88093 | 59932 | 33270 | 1449548 |

### SYSTEM B

| YEAR | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Totals |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Year Total | 87000 | 286000 | 337944 | 548831 | 637662 | 214437 | 215324 | 215324 | 168671 | 107662 | 2818855 |
| Discount Fact | 0.870 | 0.756 | 0.658 | 0.572 | 0.497 | 0.432 | 0.376 | 0.327 | 0.284 | 0.247 | |
| N.P.V | 75690 | 216216 | 222367 | 313931 | 316918 | 92637 | 80962 | 70411 | 47903 | 26593 | 1463628 |



Undiscounted Cash Flows



15% Discounted Cash Flows

Figure 6. Discounting

decision maker would prefer system B—$2,818,855, as compared to $2,907,511 for system A. However, when a 15 percent discount factor is used, system A has the lower life cycle cost—$1,449,548 as compared to $1,463,628 for system B.

In some respects the application of discounting can be counter to the *philosophy* of life cycle cost. That is, life cycle cost encourages a program manager to spend additional funds on R&D and production in order to save future money on operation and support. Discounting diminishes the effect of this. [Ref. 19:p. 80]

There is difficulty in determining an appropriate discount factor. For business, selection of the discount factor is usually guided by the return they could safely get investing their money elsewhere. However, what is an appropriate discount factor for the government? Long argues that even though the government is not guided by profit, the government also has other things it could use its money for, not the least of which is to pay off its debt to avoid future interest. An appropriate discount factor for the government is, therefore, the interest rate on its loans. [Ref. 19:p. 81] Current practice in the U.S. Department of Defense is to use a default of 10 percent regardless of the economic climate.

The cost analysis requirements discussed in this section are broad indicators to some of the factors that are an adjunct to life cycle cost analysis. The cost breakdown structure, baseline systems, discounting and the application of inflationary indicies are tools to the analysis process, and factors that need to be considered and resolved before commencing the quantative analysis.

## E. SELECTION OF A COST ESTIMATING TECHNIQUE

In *An Introduction to Cost Estimating,* Batchelder etal. define a cost estimate as "a judgement of opinion regarding the cost of an object, commodity or service...[that] may be arrived at formally or informally by a variety of methods." [Ref. 14:p. 1] There are generally considered to be three methods to cost estimating: the analogy, cost estimating relationship, and engineering techniques. To develop cost estimates any one or combination of the techniques are used.

### 1. Analogy

The analogy method is a comparison with the attributes and costs of similar systems and programs to estimate the cost of the system being analyzed. The comparison can either be direct or scaled to account for differences between the programs. Mathematically the relationship between the estimate and the baseline system is represented as $y = \lambda x$, where $\lambda = 1$ if the comparison is direct, or other than 1 if a scaling factor is applied. An example of the analogy estimate, in its simplest form, is that if it cost X dollars to procure a particular equipment, and it costs Z dollars to operate and support it each year, then the life cycle cost of a similar system over a 10 year life cycle will be $Y = X + 10Z$. If using scaling, it may be determined that because the new equipment has twice as many critical components as its existing counterpart, a scaling factor of 2 should be applied. Therefore, the life cycle cost will be $Y = 2(X + 10Z)$.

### 2. Cost Estimating Relationships (CER)

The cost estimating relationships method is a statistical technique, also known as parametric estimating, which develops, using regression analysis, a generalized relationship between system characteristics and cost. Like analogy, it uses historical data from similar systems. But unlike the analogy method, it applies statistical analysis to fit a line between data points, called explanatory variables, in an attempt to find a relationship between them and cost. The explanatory variables may be input parameters such as physical characteristics, or output parameters such as performance or other measures of effectiveness. The technique can be applied at a very macro level, or to individual cost elements at a lower level of the cost breakdown hierarchy and aggregated. Mathematically this relationship is represented as $y = \sum f(x)$. The relationship may be linear in the form of $y = a + bx$, or non linear such as exponential in the form $y = ab^{x}$.

### 3. Engineering Estimate

The engineering approach, also called **bottom up** estimating, is an examination of the costs, and characteristics that influence costs, at the lowest level. The engineering approach separates out segments of work into labor, material costs, tooling, documentation, fuel, repair parts etc., which are then summed to progressively higher levels until a total cost estimate is obtained. Mathematically this is represented as $y = \sum(p_i . q_i)$, where p is the cost, and q is the quantity. For example, to estimate the maintenance manpower cost component of operation and support costs, the starting point would be the frequency of failures, and the frequency of preventative maintenance. To these would be applied the mean time to repair, to obtain the mean maintenance man-hours for the operating cycle. This would then be applied to the costs for personnel at the various skill levels involved to obtain the maintenance manpower costs. This estimate would be added to estimates obtained in similar ways for the other components of cost to obtain the total operating and support costs of a system. The engineering approach can be used to estimate all aspects of life cycle cost.

### 4. Advantages and Disadvantages to the Estimating Techniques

The estimating techniques are not mutually exclusive, and may be combined in the analysis. However, each of the methods have advantages and significant disadvantages to their use. The analogy method has the advantage that it is by far the least complex and time consuming approach. Since very few systems are totally new, the value of analogy is that it can be easily applied to components of the system for which there is some experience and actual data. However, if significant scaling is required the credibility of the method decreases markedly, since it relies heavily on the opinion of the analyst as to what the scaling factor should be.

The cost estimating relationship approach has the advantage that it can be applied to varying levels of the cost breakdown structure as the detail of the decision requires, and availability of the data dictates. This approach is most useful for estimating the production and construction components of life cycle cost, where it has been used with some success. For operating and support costs the value of its application is at a more macro level. At a detailed level of analysis the parametric method is not well suited to distinguishing between design differences that influence operating and support costs. A further criticism is that, by its nature, a cost estimating relationship tells a great deal about the factors that lead to the construction of the estimate, but it may bear little relationship to the factors driving cost in the system being analyzed. Related to this is the problem that it assumes that the costs of operating and support of comparable systems are related in some way to the costs of supporting the system being analyzed. These are problems caused by the practicalities of trying to estimate cost on the basis of historical data for similar systems. As pointed out by Sovereign:

> In producing CERs and then treating them as statistical forecasts, we are violating the fundamental principle of statistics, which is that our data must be samples from a definable, single population....The reason we design new systems is that they are different, otherwise we would buy more of the old ones. [Ref. 20:p. 37]

The engineering approach is potentially the most useful of the cost estimating techniques if all relevant costs are considered. On occasions however, the engineering approach may not be reliable because the estimator will only include costs they are aware of [Ref. 14:p. 5]. Whilst this criticism can be leveled at all the methods, because of their application at a more macro level, the parametric and analogy methods tend to *sweep up* costs that may be missed in an engineering estimate. For example, in estimating the costs of construction, the costs of rework, planning time and quality control are uncertain and easy to underestimate [Ref. 14:p. 5]. In estimating operating and support costs, the costs of repairing failures during burn in, or due to operator and maintainer error are difficult to predict. These are only a problem if the decision warrants that level of accuracy. The major disadvantage of the engineering method is that it is extremely time consuming and requires a great deal of data. That said, it is the most useful way to analyze design tradeoffs, differentiate between the life cycle costs of alternate designs, and conduct level of repair and other logistics support analyses and tradeoffs.

### 5. Timing in the Application of Different Estimating Techniques

The different advantages and disadvantages of the cost estimating techniques lend the techniques to application during different times in a system's life cycle. During Concept Exploration where alternative approaches to satisfying a mission need are being explored for affordability, analogy or gross parametric techniques are appropriate. As the concept is defined, and a broad design determined, parametric methods to a lower level of detail, and analogy with appropriate scaling can be used. As the design becomes firm, or alternate *off the shelf* designs are being evaluated, engineering methods can be brought in to the analysis. To reiterate, the different methods of estimating are not mutually exclusive and a combination of techniques can be used as appropriate.

## F. LIFE CYCLE COST MODELS

A cost model is nothing more than a representation of the real world that can be applied to a specific situation to obtain a cost estimate. A cost model may use any or all of the estimating techniques discussed above to attempt to predict the real world costs of a system. The estimate may be manually generated or, as is increasingly the case, be generated using a software model that is run on a computer.

Life cycle cost models proliferate. In the mid 1970's it was estimated that there were over 1000 models [Ref.21]. As was observed at the same time by a U.S. Air Force working group examining life cycle cost models:

> ...every system, subsystem, component has certain unique characteristics performance [sic] that influences its development, acquisition and operating and support costs. Because these characteristics vary, and because of the different design issues that occur throughout the life cycle

> of a system, subsystem, component, new life cycle cost models are being developed at a rapid rate. [Ref. 22]

The passage of time has seen this prediction materialize. Today one observer noted, the number of life cycle cost models is probably closer to 3000 [Ref. 4]. Many of these models however, are specific purpose models with only limited application now that they have served their purpose.

Life cycle cost models can be considered to fall under one of four general categories. (The Air Force's life cycle cost working group defined ten categories of life cycle cost models, there is however repetition in their categories.) The four categories are:

- **Accounting Models.** In accounting models costs are categorized, aggregated to a total, and displayed as a spread of expenditures. All life cycle cost models are accounting models to the extent that they all, to some degree, aggregate and categorize costs. What differentiates accounting models is that this is all they do.
- **Cost Estimating Relationship Models.** In cost estimating relationship models the parametric techniques of statistical regression discussed above, are used to relate aspects of life cycle cost directly to parameters of design, performance or the logistics environment. Cost estimating relationship models include what are called factor models which apply a derived *factor* to key system parameters to arrive at costs.
- **Analytical models.** Analytical models use mathematical equations to describe the relationship of one variable to another. What differentiates analytical models from cost estimating relationship models is that the equations are not statistically derived. Analytical models for the most part employ the techniques of engineering estimating described in the previous section. Special purpose analytical models include: level of repair analysis models, which determine the most cost effective maintenance policy; inventory models, which show the effects of inventory on cost; logistic support cost and life support cost models, which show the effect of design on logistics cost; and manpower models, which specifically relate design parameters to their effect on manpower and manpower cost.
- **Simulation Models.** In simulation a model is developed that represents the particular problem, and then experiments are performed on the

> model by altering the controllable variables to determine the impact on cost. [Ref. 23:p. 596] What differentiates simulation models, is that the experiments are performed by conducting many trials, using random numbers generating from a probability distribution that represent the range of probable values, and observing their effect. Simulation models are used to determine the impact of basing, maintenance planning, and spares and support policies on logistics costs.

The majority of life cycle cost models are either cost estimating relationship models or analytical models. Some of the better known cost estimating relationship models include those developed by the RAND corporation for aircraft airframe, avionics and missile production costs; and the RCA Price series of models. Because the regression equations in cost estimating relationship models require constant update to reflect new data points, and are usually very system specific, most models are developed in house, on an as required basis by the user. Often older models are *calibrated* to reflect new data when needed. Examples of modeling with cost estimating equations is provided in the appendix.

The breadth of analytical models and their uses is extensive and reflects the diversity of use of life cycle cost analysis. Most models tend to concentrate on a specific task. A common approach to this in many analytical models is to narrow the costs under consideration to concentrate purely on logistic costs. These are variously known as life support cost models or logistic support cost models.

A consequence of the specificity of models is that, as a RAND study of life cycle cost models in the late 1970's found:

> None of the models discussed here—nor any others that we know of—provides full coverage of the life cycle cost estimates or the major driving costs, which means that comprehensive cost estimates require a hybrid combination of generalized models or a combination of models and ad hoc methods. [Ref. 24]

Many of the models which the RAND and Air Force studies reviewed are still in use, although updated and often modified where necessary, to now run on personal computers. As one long time observer of life cycle cost noted "nothing much has changed" [Ref. 21]. Discussions which the author had with practitioners of life cycle cost analysis in the U.S. indicated that the conclusion of the RAND study still largely holds true for the life cycle cost models used in all the U.S. services today. However, with the widespread use of personal computers there have been some more recent efforts at producing more comprehensive life cycle cost models. Two examples are CASA, the Cost Analysis Strategy Assessment Model of the Defense Systems Management College, and a commercial product, EDCAS produced by a company called Systems Exchange. There is also an effort currently in progress in the Naval Sea Systems Command (NAVSEA) Logistics Policy and Appraisals area to develop a new comprehensive analytical Navy life cycle cost model [Ref. 25].

The selection of a model or models will largely depend on what the purpose of the analysis is, and at what stage in the life cycle the analysis is conducted. The timing in the application of a particular model is dependant on the estimating techniques used, and the same considerations apply as in selecting the appropriate technique. As a broad guide on the use of models, models based around parametric costing techniques are usually used for affordability decisions conducted early in the life cycle, and are for the most part developed for the specific analysis. In selecting amongst alternative designs either in the design process or for source selection, and for conducting logistics analysis, analytical models based on engineering data are appropriate, although a hybrid cost estimating and analytical model might also be used depending on the particular problem to be solved. Simulation models are usually most applicable in conducting logistic analysis. While it makes sense to use an existing model if one is available to solve the problem, caution should be exercised to ensure that the model fits the problem rather than making the problem fit the available model.

## G. SENSITIVITY AND UNCERTAINTY ANALYSIS

Sensitivity, and uncertainty analysis are valuable techniques to apply once a model has been developed and run. Sensitivity analysis examines the impact of changes in input parameters on the result produced by the model. Varying the input parameters over a range to see the impact on cost can help highlight the major factors effecting cost, and show the effects of tradeoffs on cost.

There is considerable uncertainty in cost estimates. Uncertainty analysis is an attempt to come to terms with the possible ranges of the estimate and their effect on decisions. Although often used synonymously risk and uncertainty are technically different. Risk implies that an outcome is a random event stemming from a known probability distribution whereas uncertainty, while probabalistic in nature, is characterized by an unknown probability distribution [Ref. 26:p. 17]. In practical terms, risk reflects statistical errors in estimating, while uncertainty is due to an inability to measure cost or other parameters precisely, and to the unknown changes in requirements, policy, design and schedule that invariably occur. There are techniques for dealing with risk, and these will not be entered into here. Two excellent sources for reference are Long, J. A., *Life Cycle Costing in a Dynamic Envioronment,* [Ref. 19] and a supplement to Batchelder, C.A. etal. *An Introduction to Equipment Cost Estimating*. [Ref. 14]

Life cycle cost estimating is a normative approach [Ref. 27] That is, its input parameters and output cost are those that should occur, not those that will actually occur. It makes assumptions about these input parameters, system characteristics, and support and deployment policies, which if changed may have significant effect on the estimate. These elements of uncertainty can be partially dealt with by using sensitivity analysis to produce a range of costs that reflect the range of likely outcomes. This is particularly important when using life cycle cost to distinguish between alternatives, as an incorrect decision may occur with out these considerations. This is illustrated in Figure 7.

In Figure 7 the diagrams represent the probability distributions for a range of costs that reflect the uncertainty in the cost estimates. Case 1 in Figure 7 represents the ideal where the range of estimates between alternatives is distinct. Without consideration of range, a point estimate would still lead to selection of system A on the basis of lowest cost. In case 2, while a point estimate would indicate the cost of A is still less than B, there is some probability that the actual cost of A will be greater than B. This is the overlap. If the overlap is large a point estimate could give the wrong decision. In case 3, the expected cost of B is only slightly lower than A, and therefore would be selected on the basis of a point estimate. But given the range of B compared to A, it is much less certain that B will actually be less than A, so consideration of the point estimate alone, without any concern for the confidence of this estimate, may lead to a wrong decision.

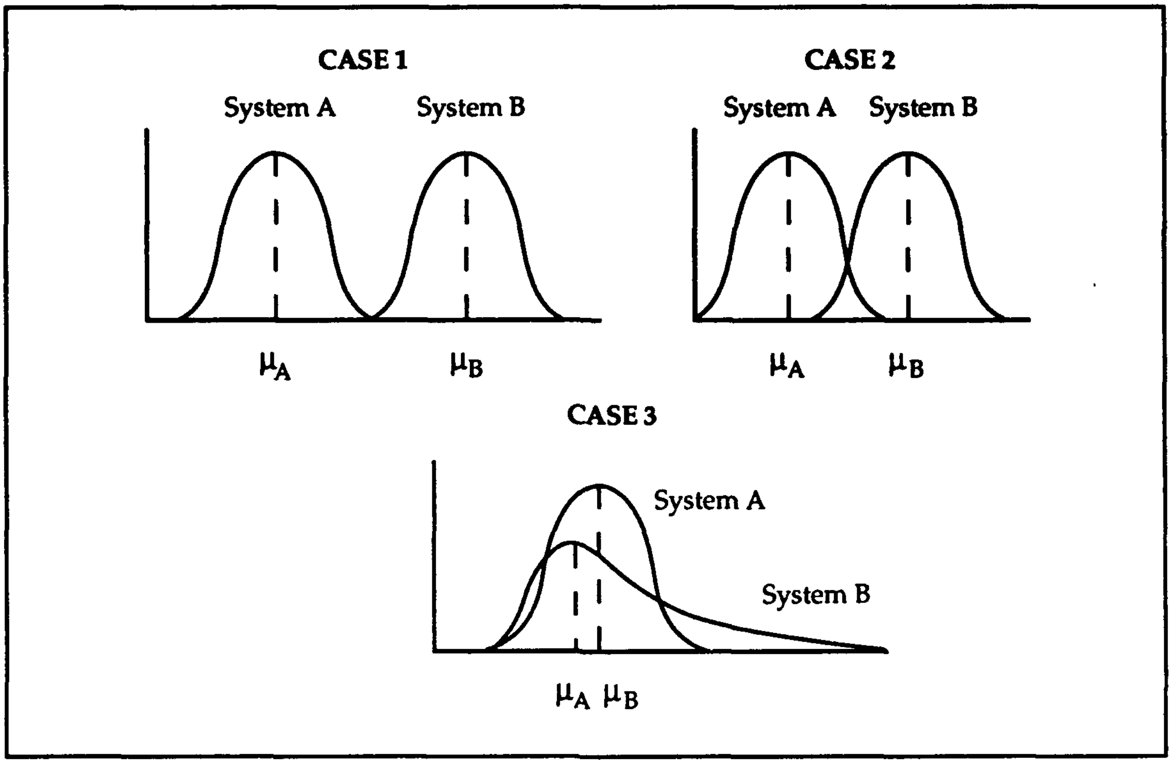


Figure 9. Uncertainty [Ref. 19:p. 42-43]

Sensitivity and uncertainty analysis will, therefore, indicate to the decision maker the confidence that should be placed in the estimate, and the effect of altering critical parameters and assumptions on the result. In this, they augment the central analysis. The value of these exercises in the analysis process is to promote a better understanding of the factors effecting cost, and the limitations of the analysis. To be aware of these will likely result in better decisions from the estimate.

## H. CONCLUSION

This chapter has discussed some of the the key points and issues of life cycle cost as a decision making tool. It has done so in the context of a general life cycle cost analysis approach both to illustrate the process and to provide a framework for the discussion. The relevance of the points brought out in this chapter will be enlarged upon in the following chapter where the current state of life cycle costing in the U.S. Department of Defense will be examined. This chapter can be thought of as the theory, and the following chapter the practice of life cycle cost. This chapter has examined some of the techniques and vocabulary necessary to understand the practice of life cycle cost analysis.

The major points of this chapter are that life cycle cost has several uses as a decision making tool: to evaluate affordability; to assess competing designs for least life cycle cost and to influence designs in this direction; and to conduct design and logistic support tradeoffs. However, these decisions are just different points along the same continuum, and an analysis started for affordability decisions should, as data becomes available and other estimating techniques become appropriate, be reviewed and revised until ultimately it is also used for making decisions about the logistic support environment.

Life cycle cost concerns the tradeoffs of reliability, maintainability, and supportability—the operating and support cost drivers, with any increases in R&D and production costs that may result. Life cycle cost analysis should therefore, be thought of in the larger sense as cost effectiveness analysis.

The issue of data has been discussed. Three tupes of data are needed for life cycle cost analysis: resource data, physical and performance characteristics, and program data. Of these resource data is likely to be the most difficult to obtain, particularly data on indirect costs. The input-output analysis approach has been examined as one means for obtaining this type of data. Also discussed have been the arguments on how important accurate data is for the purpose of life cycle cost analysis.

Already in this discussion of the theory of life cycle cost analysis, several problems and criticisms have been identified that are likely to have consequence to its practice. These include the limitations of the techniques, the proliferation of cost models, and the treatment of uncertainty. Practically how these effect life cycle cost analysis will be examined in the following chapter.

# III. LIFE CYCLE COSTING IN THE U.S.

This chapter will explore where and for what purpose life cycle cost analysis is incorporated in the U.S. Department of Defense, and who the major players are in the process. The process described will be for major weapon systems programs, also known as Acquisition Category One (ACAT I) programs. Less than major system programs follow a similar, if less closely regulated process. Additionally, this chapter will describe the major data source for life cycle cost analysis in the U.S.—the VAMOSC system. The focus of this chapter will be predominantly with the U.S. Navy to illustrate the process and organization of life cycle costing. The appendix to this study complements this chapter. In the appendix two examples of the U.S. Navy's application of life cycle costing are discussed—the SSN 21 SEAWOLF Submarine Program, and the F/A 18 HORNET Fighter Aircraft Program.

## A. THE FRAMEWORK FOR LIFE CYCLE COST IN THE U.S.

The framework for life cycle cost analysis in the U.S. are the various regulations that govern the weapons system acquisition process and its related activities, and the organizations that implement them. An examination of the regulations should define how life cycle cost is viewed officially, and how it should be used. However, the regulations will not necessarily indicate whether in practice life cycle cost is accorded the same attention. This section will review the regulations concerning the acquisition process, design to cost, source selection, and integrated logistic support to discern the official U.S. position on life cycle cost. Additionally, the functional organizations responsible for life cycle cost will be discussed. Some conclusions and observations about the regulations and the organizations will be included in an overview discussion.

### 1. Life Cycle Cost in The Acquisition Process

The policy basis for weapons system acquisition process is Office of Management and Budget (OMB) Circular A-109 which details policy for major acquisitions in all U.S. federal agencies. The Department of Defense (DOD) interpretation of this policy is DOD Directive (DODD) 5000.1, which in turn is implemented by DOD Instruction (DODI) 5000.2, *Defense Acquisition Program Procedures*. Each of the military services also have their own regulations which compliment DOD and Federal policy guidelines.

The acquisition process described by the above regulations segregates acquisition in to five milestones and phases. These phases correspond to the phases of an equipment's life cycle. The acquisition process is briefly illustrated at Figure 8. At each milestone major programs are reviewed by a Defense Acquisition Board (DAB). The DAB is the senior DOD acquisition review board and is chaired by the Under Secretary for Defense for Acquisition, also known as the Defense Acquisition Executive (DAE). The Secretary for the DAB is the Vice Joint Chief of Staff, and each of the services are represented on the board. There are also ten DAB Committees that report to the DAB on various aspects of a program as it progresses through the acquisition process.

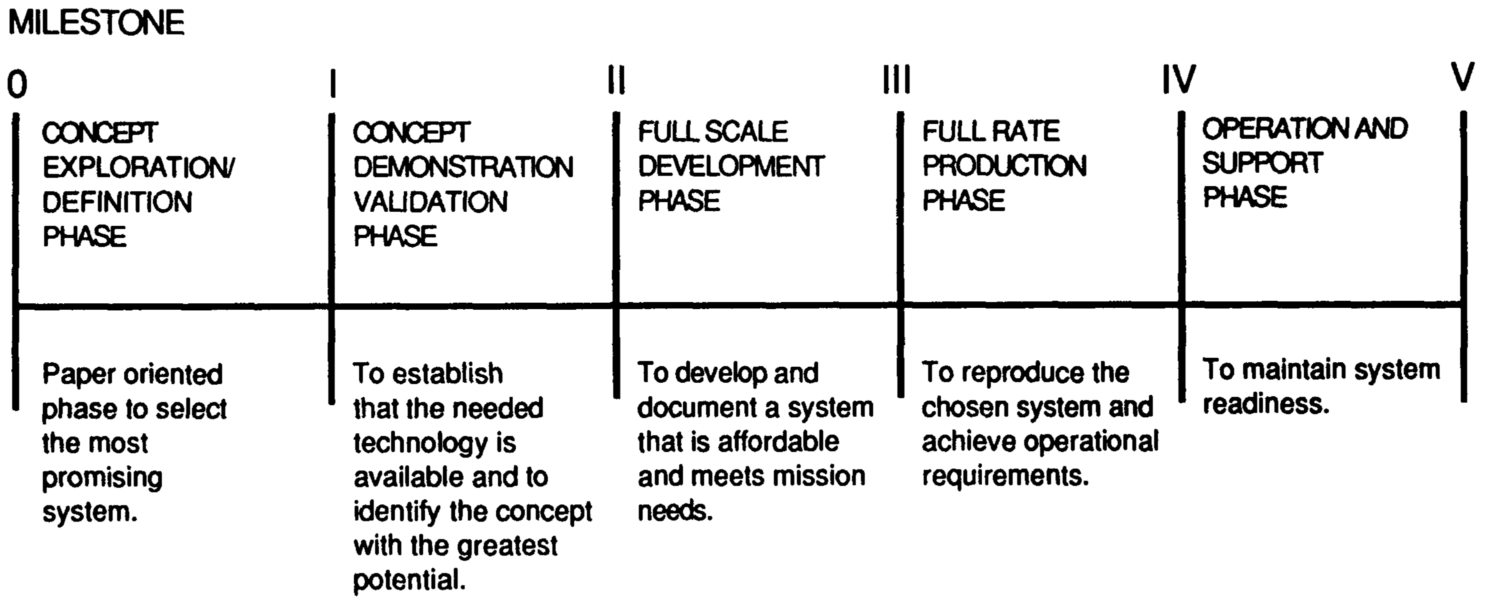


Figure 8. The Acquisition Process

Life cycle cost is given considerable emphasis in the policy and implementation guidance for the acquisition process. Circular A-109 directs that a major system acquisition management objective will be to

> Maintain a capability to: • Predict, review, assess, negotiate and monitor costs for system development, engineering and design, demonstration, test, production, operation and support (i.e., life cycle costs) • Assess acquisition cost, schedule and performance experience against predictions, and provide such assessments for consideration by the agency head at key decision points • Make new assessments where significant costs, schedule or performance variances occur • Estimate life cycle costs during system design concept evaluation and selection, full-scale development, facility conversion, and production, to ensure appropriate trade-offs among investment costs, ownership costs, schedules, and performance • Use independent cost estimates, where feasible, for comparison purposes. [Ref. 28:p. 5]

The importance of this objective is to lay the foundation for a policy to procure effective, affordable and supportable systems to meet the mission needs of the services.

The theme of affordability is continued in DODD 5000.1 [Ref. 29:p. 5-6], which establishes checks and balances during DAB reviews to ensure that it is reviewed at every milestone. In assessing affordability, DODD 5000.1 directs that: "a major defense acquisition program shall not be started unless sufficient resources ...can be programmed to support projected development, testing, production, fielding, and support requirements."

In addition to issues of affordability, DODD 5000.1 also introduces sustainability and supportability as decision considerations. These it states, should be a primary objective of the acquisition strategy, given early consideration and the same emphasis as issues of performance and schedule. Additionally, the directive also calls for "...funding to design-in reliability and support characteristics....," with the intention of reducing life cycle cost, early in the program.

The practicalities of implementing this policy are dealt with in DODI 5000.2. [Ref. 30] Specifically, this instruction calls for life cycle cost to be addressed in the Mission Need Statement for decision at Milestone 0, the System Concept Paper for decision at Milestone I, and the Decision Coordination Paper for Milestones II and beyond. These papers are documents submitted by the program manager to the DAB for milestone review. The annexes to both these papers also provides some insight. Annex C is a *Resource Cost Track Summary*. This requires estimates for the cost at each of the phases of the systems life cycle, and for an aggregated life cycle cost estimate. Annex E is a *Summary of Life-Cycle Cost Alternatives*, which as its name implies, is an assessment of the total costs of ownership of alternate means of meeting the mission need that a program is intended to fill. Also of consequence is Annex B, which lists the cost, schedule, performance and supportability goals of the program. It is worth noting that despite the emphasis elsewhere, when it comes to defining goals and thresholds these are not defined in terms of life cycle cost.

### 2. Life Cycle Cost in Design to Cost

DODD 4245.3 [Ref. 31] is the defense policy for design to cost. This policy is implemented by the pamphlet *Joint Design-To-Cost Guide: Life Cycle Cost as a Design Parameter* [Ref. 6] These documents establish life cycle cost as the criteria for design to cost. As the latter of these documents states

> Design to Cost Goals should be established for all elements of future Life Cycle Cost which are design controllable. Acquisition strategies must then be structured to achieve these goals. [Ref. 6:p. 4]

What is important is that rather than just sailaway or flyaway cost being the criteria for design to cost, life cycle cost is the constraint to which affordable design should be oriented. This is further emphasized by the requirement placed on the program manager in a design to cost program to:

> ...identify high-risk or high-cost components, which are the major life cycle cost drivers that provide the greatest opportunity for design tradeoffs. During contract performance, containing *cost driver* costs shall be emphasized. [Ref. 31:p. 4]

Design to Cost goals and thresholds are required by the regulations to be firmly established during the Concept Demonstration and Validation phases of the acquisition cycle, and measured during contract performance. They also recommend that the contractual mechanisms of incentives and awards be used to motivate the contractor to attain the required levels of reliability and supportability.

### 3. Life Cycle Cost in Source Selection

Having established the requirement in the acquisition and design to cost regulations to acquire affordable, supportable systems; it is perhaps surprising that life cycle cost is given little attention or priority in the source selection regulations for selecting amongst contractors during competitive procurements. The directive on source selection, DODD 4105.62 [Ref. 32], only defines cost to include " both unit production cost and life cycle cost" very late in its discussion. Even then, this directive only talks in terms of cost, not life cycle cost specifically.

It advises that although cost is always a criteria in source selection, it is only important as a "discriminator in the source selection decision when differences among proposals relative to other factors is small and when cost proposals have a high degree of realism and credibility."[Ref: 32:p. 5] Thus, if any emphasis on life cycle cost can be construed from this regulation, its importance in source selection is played down. While the absence of specific concern for life cycle cost may be intended to give programs flexibility to tailor selection criteria as appropriate to their particular program, it is perhaps indicative of the real weight placed on life cycle cost in source selection.

### 4. Life Cycle Cost in Integrated Logistic Support

The regulation that governs Integrated Logistic Support (ILS), DODD 5000.39 [Ref. 7], discusses ILS in the context of the life cycle management of major systems. While not specifically mentioning the term life cycle cost, it does address such substitutes of life cycle cost as reliability, maintainability, and supportability—issues effecting the operation and support cost component of life cycle cost. Specifically, it directs that in the acquisition process "starting with concept exploration," consideration should be given to "system characteristics that best meet readiness and support cost objectives in fielded systems." It further states that in considering support in the acquisition process "support costs and readiness drivers" should be identified as "targets for improvement," and issues of reliability, maintainability and supportability should be assessed in system acquisitions and be the object of design tradeoffs and contractor incentives. It is worth noting that in the Navy instruction on ILS—SECNAVINST 5000.39A [Ref. 33], the use of life cycle cost criteria for these design and support tradeoffs is specifically mandated.

In ILS the primary vehicle to achieve supportability considerations is the Logistic Support Analysis (LSA) conducted in accordance with MILSTD 1388. LSA can be considered as the application of analytical tools to evaluate alternate designs, support concepts and tradeoffs among ILS elements. In essence there are a wide variety of analytical methods used in LSA, and life cycle cost analysis is just one of these, although an important one.

### 5. The Major Organizations Involved in Life Cycle Cost Analysis

It is the Program Manager that has overall responsibility for getting a program through the acquisition process. In Navy programs, the program manager works within the Naval Sea Systems (NAVSEA), Naval Air Systems (NAVAIR) or Naval Space and Electronic Systems (NAVSPAWAR) commands. To assist in the preparation of cost estimates each program draws upon the expertise of the *cost shop* within the systems command. These are NAVSEA 017, NAVAIR 524, and NAVSPAWAR 10J. However, the expertise of these areas is primarily for research and development cost, and for production cost estimates. As a consequence, outside contractor resources are commonly used for the preparation of operating and support cost estimates.

As part of the Navy's internal review and approval process, before sending programs to the DAB, an independent estimate of a program's costs is conducted by the Naval Center for Cost Analysis. If there is a significant difference between the independent estimate and the program manager's estimate this will usually be resolved before a program goes forward. However, if the difference cannot be resolved two estimates will go forward. This contrasts with the approach of the other services which *reconcile* any differences and only put forward one estimate. [Ref. 34]

Prior to formal DAB review, cost estimates are reviewed by the Cost Analysis Improvement Group (CAIG). The CAIG is made up of various members of the DAB and service appointees, and is staffed from the Office of the Secretary of Defense PA&E. The CAIG are the *principle advisory body* to the DAB "on matters related to cost" [Ref. 35]. The CAIG Review is primarily concerned with the completeness and quality of the estimates. Since only 3 weeks are given for a CAIG Review, it is by necessity at a more macro level than that of either the program or the independent estimate. As a result of their review of a program's estimates, the CAIG produce a CAIG Report that is submitted to the Under Secretary of Defense for Acquisition (the DAB President). The approval process and the relationships between the different areas responsible for cost analysis is illustrated in the diagram at Figure 9.

The CAIG as the ultimate arbiter of cost, sets the standards and procedures for life cycle cost in all of DOD. They publish life cycle cost element definitions and methodology guidance. In this role, their interest with life cycle cost is primarily in the estimating methodology and its assumptions.

Another functional area with interest in aspects of life cycle cost are the services integrated logistics support communities. In the Navy, ILS is ultimately the responsibility of the Assistant Secretary for the Navy Shipbuilding and Logistics (ASN[S&L]), although there are also specific responsibilities vested with some of the other assistant secretaries for some aspects of ILS. [Ref. 33] The practicalities of conducting ILS however, are the responsibilities of the various system commands. In NAVSEA it is the Deputy Chief Engineer for logistics (CHENG-L) that is accountable for ILS and setting NAVSEA logistics policy and practices. Under CHENG-L there are various directorates that set specific logistics goals, and provide functional support to program managers and their ILS managers in carrying out the ILS for systems acquisitions.

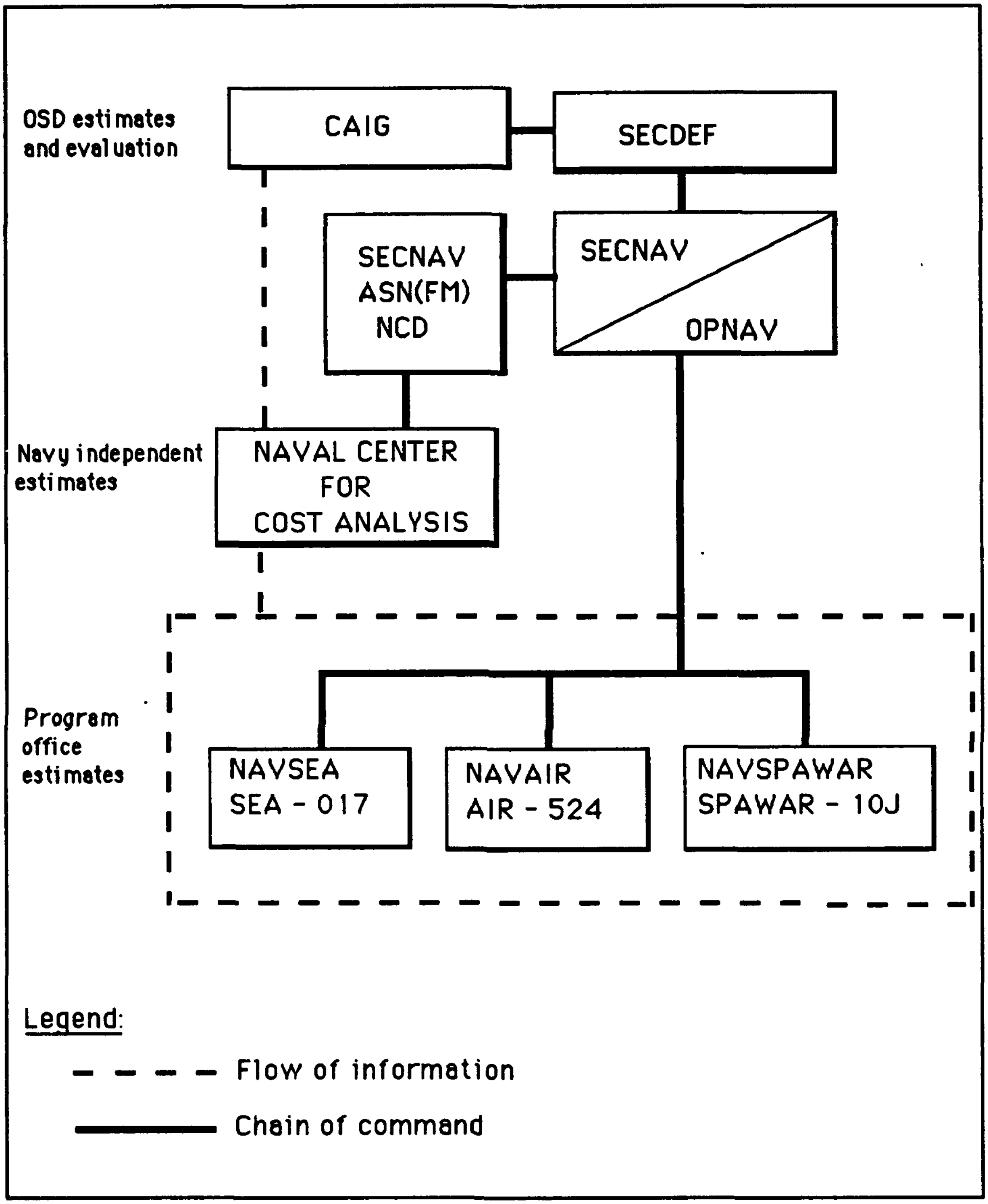


Figure 9. DOD/DON Organization For Cost Analysis [Ref. 36]

What is important in the Services logistics organization is not the specific responsibilities of the individuals involved, but to realize that there exists in this organization other groups who have their own particular interests in life cycle cost as a means to prompt consideration of reliability, maintainability and supportability in design, and as the basis for logistics tradeoffs.

### 6. Overview of the Regulations and Organization for Life Cycle Cost Analysis in the U.S.

Reviewing the regulations and organizations with an interest in life cycle cost indicates DOD's prescribed approach to the use of life cycle cost analysis. Life cycle cost is given specific attention in the regulations and instructions that govern acquisition and design to cost, but less specific attention in the regulations that cover integrated logistic support and source selection. Thus while life cycle cost may not be accorded the regulatory recognition for all its potential uses, it at least should be accorded a fair degree of institutional emphasis. This appears, at least in theory, also to be backed up by a costing and approval process that receives the input and oversight of a number of different organizations with an interest in life cycle cost. This is the regulatory and institutional framework in which life cycle cost analysis is conducted in the U.S. It remains to be seen whether in practice life cycle cost is really accorded any emphasis in decision making.

## B. DISCUSSION OF THE PRACTICE OF LIFE CYCLE COSTING IN THE U.S.

The problem with analyzing life cycle cost in the U.S. is that there is not consistency in its application, or its use in decision making. It would be easy to say that life cycle cost is never a major consideration in decision making.

However, as the example of the F/A-18 case in the appendix shows, there are cases where a life cycle cost analysis approach have been applied with considerable success. Similarly, although this is yet to be resolved, the V22 Program was not given favorable review by the CAIG, and at this stage, approval to progress to production has been withheld largely on the basis of the affordability of its operation and support costs [Ref. 37]. However, this author's research indicates that in practice, cases such as these are more the exception than they are the rule, and that in most if not all instances, very little emphasis is really placed on life cycle cost as a basis for making decisions.

Rather than life cycle cost, the institutional emphasis is on acquisition cost. Commonly, a reduction in operating and support costs is used by the program office as one of a number of reasons to have a particular program approved, but there is little indication that this is actually an overriding consideration in program approval. And while most, but not all, programs produce a life cycle cost estimate in order to meet the requirements of the acquisition regulations, in the majority of cases, it is done in order to have the *boxed ticked* on the way through the approval process.

In the review process, the Naval Center for Cost Analysis are primarily concerned with the accuracy of the acquisition cost estimates. Unless they are asked, or they perceive a particular problem with operating and support costs, they only conduct a truly independent estimate of a program's acquisition costs. This is not to say that the Naval Center for Cost Analysis do not review the operating and support costs, but that they do so in considerably less detail than with the acquisition costs. Similarly in there deliberations, the CAIG while briefed on operating and support costs by the program office, are also more concerned with the acquisition cost of a program and its affordability over the acquisition phases, than with costs to be incurred in operating and support.

These findings are backed up by an earlier study conducted in 1979 that surveyed over 300 people in the Congress, DOD and industry associated with defense program management in the U.S. [Ref. 38]. Amongst the respondents, the survey indicated that 75 percent considered unit production cost to be more important than life cycle cost, and that in their decision making 88 percent said they directed their attention to near term acquisition cost rather than long term operating and support costs. Of interest also is that a significant majority of those surveyed believed that there was insufficient guidance given on life cycle cost. This is despite the fact that all the relevant regulations discussed and cited in this study had been promulgated at the time. Only the regulation on Design to Cost, DODD 4245.3, was in a different form as DODI 5000.28 at the time of the survey.

There are several reasons for the widespread lack of real concern for determining life cycle cost. One is the orientation of the DOD. A significant factor in the U.S.'s place as a military power is the technological sophistication of its weapons systems. This has promoted a mindset that places great importance on the acquisition of new and more capable weapons systems. From this view point the emphasis is on getting shiny new equipment that goes faster and shoots further. The costs of actual ownership are secondary. McClendon [Ref. 4] argues that this is an endemic problem which reflects a general lack of concern for the future not only in DOD but the society as a whole. The budgetary process which places most interest and accountability for monies to be spent in the near term than the long term promotes this view.

The organizational structure in Defense also provides a functionalism that does not promote decision making on the basis of life cycle cost. The concept of life cycle cost is intended to reduce operating and support costs yet, often in order to do so involves additional spending in the early stages of an acquisition in R&D and other efforts to improve the reliability and maintainability of the particular system. The program manager however, has only finite funds, and must manage his program to acquisition cost and schedule. Efforts to reduce life cycle cost often run counter to these requirements. Because the responsibility for program management and the operation and support of fielded weapon systems are separate, the program manager has no incentive to take action to reduce operating and support costs if to do so will run counter to his own interests to manage a program on the basis of acquisition cost and schedule. This is accentuated because there is no accountability for the life cycle cost estimate put forward. If a program uses as justification for its acceptance that it will reduce operating and support costs by a certain amount over the current capability, there is no requirement to live up to that estimate. In contrast, programs are held accountable for acquisition cost estimates.

In an effort to come some way to avoiding these problems, there have been moves to establish what is colloquially known as a "womb to tomb" project management organization. In this approach, rather than the program manager transition a program to functional areas on completion of the acquisition, he will also have to manage it throughout its service life. This concept is currently being applied to manage the CG 47 AEGIS Ship Program. While this is spoken of enthusiastically in some quarters, it is still too early to determine if this approach will have any long term effect.

From the stand point of the organization, interest in life cycle cost comes from two quarters—those who are interested in life cycle cost as an indicator to general affordability, and those who are interested in the detail of the reliability, maintainability and supportability tradeoffs that are inherent in the application of life cycle costing as a concept. The former of these interests is a budgeteers view of life cycle cost, while the latter is a logisticians. The functional organization for life cycle cost discussed above is along these lines. While these are complementary views to the use of life cycle cost, in practice it is the budgeteers view that dominates. This is evident in the organizations that make up the review and approval process. The Naval Center for Cost Analysis and the CAIG are primarily concerned with the estimating methodology rather than the tradeoffs that should have occurred. In the reports that a program provides during program review and approval, and in the System Concept Paper and Decision Co-ordination papers that go to the DAB, it is a total life cycle cost estimate, arrived at through gross parametric means that is usually provided. The dominance of the budgeteers view however, is a major factor in the lack of acceptance of life cycle cost as a basis on which to make decisions.

The problem with life cycle cost as a budgetary tool, in this authors opinion, is that it is a role for which the techniques of life cycle cost estimating are currently not well suited. When used in this way there is an expectation that the overall estimate will be accurate. This view holds that the operating and support estimates be at least as accurate as acquisition cost estimates if decisions are to be made on the basis of life cycle cost rather than acquisition cost alone. However, there are two factors mitigating against this. The first, is that when projecting so far in to the future, so many factors are likely to change, that the estimate can not with any certainty include these. The second factor is that the operating and support cost data that is available does not support accurate estimates. This will be pursued in detail in the following section. In contrast, the logisticians approach does not require the same level of accuracy. From the logisticians point of view, what is of interest are the effects of different design features on cost, rather than an absolute measure of cost. With the dominance of the budgeteers view, and the limitations of life cycle cost estimating to provide the accuracy of estimates demanded, the tendance is to fall back on acquisition cost as the basis for decisions. Thus commonly, life cycle cost estimating really becomes just a tick in the box in the acquisition process.

## C. The VAMOSC System

In 1974 the General Accounting Office (GAO) in their report *Life Cycle Cost Estimating—Its Status and Potential in Major Weapons Systems Acquisition,* found that the lack of operating and support cost data was a considerable limiting factor to the use of life cycle cost in acquisition. As discussed in the preceding chapter, data is probably the most important, and at the same time, most difficult part of life cycle cost analysis. While historical data for R&D and production costs are usually readily available because of the tight reporting required of programs in acquisition, and because of contractor billing during these phases, operating and support cost data does not have the same visibility. Shortly after the GAO's comments, and in response to them, Deputy Secretary for Defense Packard established a management objective for the Department of Defense to provide a data collection system for operating and support costs. This became the Visibility and Management of Operating and Support Cost (VAMOSC) data system.

DODD 7220.33 [Ref. 39] defines the purpose of the VAMOSC to be to:

> ...permit the development of a well defined, standard presentation of O&S costs by defense system, including a display of critical logistics support costs at the subsystem level for existing (fielded) systems.

This directive goes on to specify that

> VAMOSC data can be used as a basis for decisions concerning affordability, budget development, support concepts, cost tradeoffs, modifications, and retention of current systems.

Each of the Services has their own VAMOSC system. For the Navy, VAMOSC is in two parts: VAMOSC-Ships and VAMOSC-Air. VAMOSC-Ships provides a top level cost breakdown by major platform and cost element. There are two basic cost report formats in VAMOSC-Ships. The first is the average costs for each element of operating and support costs by ship type, and the second is the costs for each element of operating and support costs for the individual ships of a particular type. An example page from each of these reports is provided in Figures 10 and 11 respectively. To these VAMOSC-Air adds a third type of report which provides more detailed maintenance related cost data by work unit code. This is called the VAMOSC MS or Maintenance Subsystems Report. This type of report is currently not available in VAMOSC-Ships. [Ref. 40] In addition to the standard report formats, special purpose reports to varying levels of aggregation and data combination can be requested from VAMOSC.

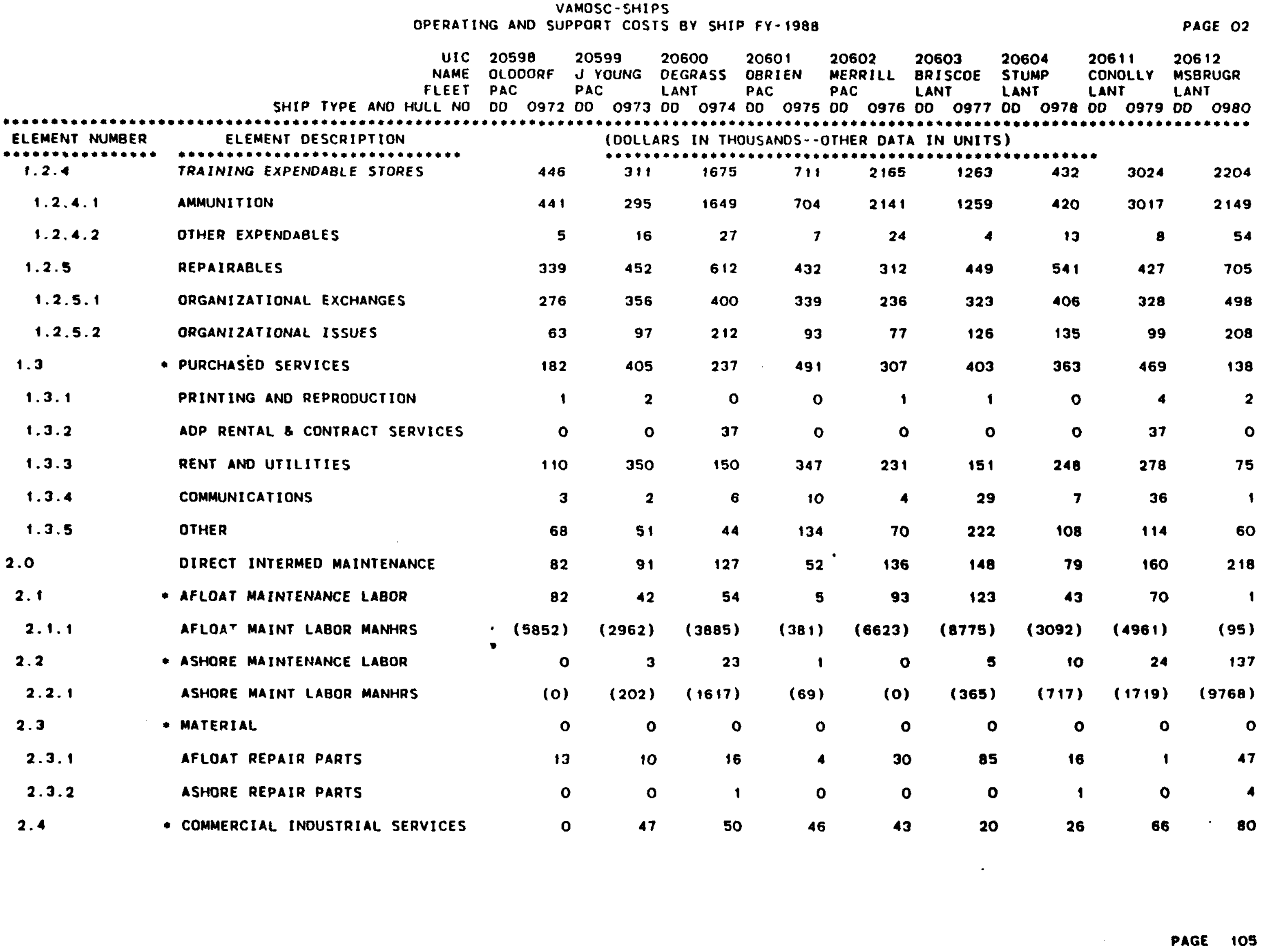
AVERAGE OPERATING AND SUPPORT COSTS OF COMBATANT SHIPS BY TYPE
FY-1988

PAGE 03

| ELEMENT NUMBER | SHIP TYPE | FF | FFG | LCC | LHA | LKA | LPD | LPH |
|---|---|---|---|---|---|---|---|---|
| | NUMBER SHIPS WITHIN TYPE | 49 | 36 | 2 | 5 | 5 | 13 | 7 |
| | ELEMENT DESCRIPTION | (DOLLARS IN THOUSANDS --OTHER DATA IN UNITS) | | | | | | |
| 3.0 | DIRECT DEPOT MAINTENANCE | 3900 | 5301 | 3864 | 24740 | 4225 | 4910 | 5434 |
| 3.1 | SCHEDULED SHIP OVERHAUL | 2469 | 2309 | 1236 | 16545 | 1904 | 2525 | 3413 |
| 3.1.1 | REGULAR OVERHAUL | 1792 | 1276 | 0 | 15304 | 0 | 1266 | 2350 |
| 3.1.1.1 | PUBLIC SHIPYARD | 461 | 379 | 0 | 15304 | 0 | 0 | 66 |
| 3.1.1.1.1 | OVERHEAD | 215 | 160 | 0 | 6957 | 0 | 0 | 24 |
| 3.1.1.1.2 | LABOR | 177 | 144 | 0 | 5354 | 0 | 0 | 27 |
| 3.1.1.1.2.1 | MANDAYS | (1208) | (1050) | (0) | (18314) | (0) | (0) | (178) |
| 3.1.1.1.3 | MATERIAL | 69 | 75 | 0 | 2994 | 0 | 0 | 14 |
| 3.1.1.2 | PRIVATE SHIPYARD | 1331 | 896 | 0 | 0 | 0 | 1265 | 2284 |
| 3.1.1.3 | SHIP REPAIR FACILITY | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3.1.1.3.1 | OVERHEAD | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3.1.1.3.2 | LABOR | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3.1.1.3.3 | MATERIAL | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3.1.2 | SELECTED RESTRICTED AVAIL | 677 | 1033 | 1236 | 1240 | 1904 | 1259 | 1063 |
| 3.1.2.1 | PUBLIC SHIPYARD | 5 | 0 | 0 | 1240 | 0 | 0 | 0 |
| 3.1.2.1.1 | OVERHEAD | 3 | 0 | 0 | 618 | 0 | 0 | 0 |
| 3.1.2.1.2 | LABOR | 2 | 0 | 0 | 438 | 0 | 0 | 0 |
| 3.1.2.1.2.1 | MANDAYS | (15) | (0) | (0) | (2944) | (0) | (0) | (0) |
| 3.1.2.1.3 | MATERIAL | 0 | 0 | 0 | 183 | 0 | 0 | 0 |
| 3.1.2.2 | PRIVATE SHIPYARD | 642 | 1033 | 0 | 0 | 1904 | 1259 | 1063 |
| 3.1.2.3 | SHIP REPAIR FACILITY | 30 | 0 | 1236 | 0 | 0 | 0 | 0 |
| 3.1.2.3.1 | OVERHEAD | 16 | 0 | 613 | 0 | 0 | 0 | 0 |
| 3.1.2.3.2 | LABOR | 12 | 0 | 491 | 0 | 0 | 0 | 0 |
| 3.1.2.3.3 | MATERIAL | 3 | 0 | 132 | 0 | 0 | 0 | 0 |

PAGE 0009

Figure 10. Example of VAMOSC Ships Operating and Support Costs by Ship Type



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                                                   VAMOSC-SHIPS
                                    OPERATING AND SUPPORT COSTS BY SHIP FY-1988                                       PAGE 02

                                                UIC  20598     20599     20600     20601     20602     20603     20604     20611     20612
                                               NAME  OLDDORF   J YOUNG   DEGRASS   OBRIEN    MERRILL   BRISCOE   STUMP     CONOLLY   MSBRUGR
                                              FLEET  PAC       PAC       LANT      PAC       PAC       LANT      LANT      LANT      LANT
                               SHIP TYPE AND HULL NO DD  0972  DD  0973  DD  0974  DD  0975  DD  0976  DD  0977  DD  0978  DD  0979  DD  0980
*************************************************************************************************************************************
 ELEMENT NUMBER          ELEMENT DESCRIPTION                       (DOLLARS IN THOUSANDS--OTHER DATA IN UNITS)
***************        ***************************                 **********************************************
  1.2.4                TRAINING EXPENDABLE STORES         446       311      1675       711      2165      1263       432      3024      2204

   1.2.4.1             AMMUNITION                         441       295      1649       704      2141      1259       420      3017      2149

   1.2.4.2             OTHER EXPENDABLES                    5        16        27         7        24         4        13         8        54

  1.2.5                REPAIRABLES                        339       452       612       432       312       449       541       427       705

   1.2.5.1             ORGANIZATIONAL EXCHANGES           276       356       400       339       236       323       406       328       498

   1.2.5.2             ORGANIZATIONAL ISSUES               63        97       212        93        77       126       135        99       208

 1.3                 * PURCHASED SERVICES                 182       405       237       491       307       403       363       469       138

  1.3.1                PRINTING AND REPRODUCTION            1         2         0         0         1         1         0         4         2

  1.3.2                ADP RENTAL & CONTRACT SERVICES       0         0        37         0         0         0         0        37         0

  1.3.3                RENT AND UTILITIES                 110       350       150       347       231       151       248       278        75

  1.3.4                COMMUNICATIONS                       3         2         6        10         4        29         7        36         1

  1.3.5                OTHER                               68        51        44       134        70       222       108       114        60

2.0                    DIRECT INTERMED MAINTENANCE         82        91       127        52       136       148        79       160       218

 2.1                 * AFLOAT MAINTENANCE LABOR            82        42        54         5        93       123        43        70         1

  2.1.1                AFLOAT MAINT LABOR MANHRS       (5852)    (2962)    (3885)     (381)    (6623)    (8775)    (3092)    (4961)     (95)

 2.2                 * ASHORE MAINTENANCE LABOR             0         3        23         1         0         5        10        24       137

  2.2.1                ASHORE MAINT LABOR MANHRS          (0)     (202)    (1617)      (69)       (0)     (365)     (717)    (1719)   (9768)

 2.3                 * MATERIAL                             0         0         0         0         0         0         0         0         0

  2.3.1                AFLOAT REPAIR PARTS                 13        10        16         4        30        85        16         1        47

  2.3.2                ASHORE REPAIR PARTS                  0         0         1         0         0         0         1         0         4

 2.4                 * COMMERCIAL INDUSTRIAL SERVICES       0        47        50        46        43        20        26        66        80


                                                                                                                              PAGE 105
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Figure 11. Example of VAMOSC Operating and Support Costs by Ship

While VAMOSC-Air covers costs to the major system and subsystem level, VAMOSC-Ships is still primarily platform oriented. Currently VAMOSC-Ships covers all major ships but only breaks out costs for the following ships systems:

- AN/BLQ-5 Sonar
- AN /SLQ-32 EW System
- AN/SPS-55 Radar
- AN/SQS-53 Sonar
- AN/SQS-56 Sonar
- ASROC
- CIWS Mk 15 (Phalanx)
- Combat Control System Mk 1
- 5/54 Caliber Mk 45 Gun
- 5/54 Caliber Mk 42 Gun
- LM 2500 Gas Turbine Engine
- Mk 117 Fire Control System
- Harpoon
- Mk 41 VLS
- Mk 26 GMLS
- Mk 86 GFCS
- AN/SPS-49 Radar

VAMOSC is really an *umbrella* management information system that draws together data collected from other large decentralized data bases. The primary purpose of these individual data bases is to provide budgetary information. The data is sourced from places such as the the shipyards, supply centers and maintenance depots for ships in service. During acquisition, data is also collected on new systems through the Logistic Support Analysis (LSA) process of MILSTD 1388 via the LSA Record (LSAR). In the Navy VAMOSC is maintained under contract by a company, Information Spectrum Inc.

VAMOSC data is intended to provide the basis for estimating operating and support costs using any of the techniques discussed in Chapter II. However, because of the limitations in the level of detail and scope of coverage with VAMOSC-Ships this places some restrictions on the techniques used when estimating the costs of ships systems. In all cases, scaling of the data from analogous hardware is likely to be required to produce the estimate

[Ref. 41:p. 96]. The use of VAMOSC data to develop operating and support cost estimates is illustrated in the appendix for the SSN 21 SEAWOLF Submarine, and the F/A 18 Fighter. The F/A 18 particularly is a good example because they applied both a top down and a bottom up approach to estimating with the VAMOSC data.

## D. DATA ISSUES

Despite the claim in the VAMOSC individual ships report for 1988 [Ref. 42] that: "the methodology used to collect and display over 84 percent of the total operating and support costs has been proved valid," many of the people interviewed by the author expressed concerns at the accuracy and comprehensiveness of the VAMOSC data. The major shortfall of VAMOSC is that it is not a true cost accounting system. There are two problems with VAMOSC's treatment of cost. Firstly, it only deals effectively with purely direct variable costs. VAMOSC does not capture and allocate all indirect costs for the systems its reporting on. Secondly, since several major systems are likely to share maintenance resources, use the same spare parts, and have common personnel operating and maintaining them, there is some question whether these shared costs are captured at all, and if they are, whether they also are allocated in correct proportion.

The problem with VAMOSC only capturing direct cost, and this being the basis of estimates, is that it does not give visibility to any changes in indirect costs that may occur. The previous chapter discussed the NARM as one way to determine indirect costs, but as was also discussed, the limitations of this model mean it is not commonly used. The result is that the impact of indirect costs are not always taken into consideration in decision making. If these were included they may have an impact.

The data problem is not in the VAMOSC system alone, but in the ability of the Department of Defense as a whole to capture and report cost. This has recently been brought out in a GAO audit of the Air Force. The criticisms the GAO made of the Air Force apply at least equally to the other services. As the GAO noted: "the Air Force is the only military service which has tried to prepare a set of financial statements" [Ref. 43:p. 2]. There is inference that the other services' accounting systems are in worse shape than the Air Force's, and that this was why they did not also respond. The GAO found in their report that

> The Air Force has no system to accurately account for billions of dollars invested in aircraft, missiles and engines. Furthermore Air Force accounting systems cannot produce the operating and support costs for weapons systems. [Ref. 43:p. 59]

There were many problems even in the Air Force's ability to accurately account for the acquisition cost of aircraft. The GAO quotes the case of the B-1 bomber which was reported to have cost $150 million each. The GAO found the cost to actually be $219 million. [Ref. 43:p. 5]

The GAO had also, several years earlier, tried to undertake a study of the problem of the increasing operating and support costs of weapons systems in all of defense. The study however had to be terminated "because data was unavailable within DOD " [Ref. 44:p. 53] In response, by 1992 each of the services are supposed to be able to accurately report the operating and support costs for weapons systems both in the inventory and planned [Ref. 44:p. 53].

## E. COST MODELING ISSUES

The absence of accurate historical cost data calls into question the basis on which cost models are constructed. All cost models rely to some degree on the identification of the relationships between cost drivers and costs, whether this be in the form of cost estimating relationships or mathematical algorithms.

The accuracy of the data has become even more of an issue in recent years with the increased availability of computer models. In the opinion of Dr McDonald from OSD PA&E [Ref. 37], one of the problems with computer models is that they have enabled people to be "intellectually dishonest." Computers have enabled many more complex problems to be modeled on a far larger scale than manual techniques would allow. Their complexity, allied with the fact that the estimates are produced on a *computer*, has meant that models are often treated as sacrosanct and their developers experts, with little questioning of the underlying assumptions or relationships in the models. These problems can be particularly acute with commercial models where the algorithms and the construction of the model may be considered proprietary.

The plethora of life cycle cost models and the variety of their uses has also meant that there is no consistent approach to what constitutes the various elements of cost, and what the relationships between cost elements are that should be represented in the models. The CAIG have a published set of cost definitions, but they are not always followed. One problem with this is that as a program develops, different models and techniques are applied at different stages of an equipment's life cycle. Because the definitions and assumptions of the models are likely to vary, the results generated from one phase of the life cycle on one model, can not be easily compared to the results generated in a different phase using different models and different estimating techniques. The same problem will occur when different models are used for comparing different designs at the same phase of an equipment's life cycle, such as in design tradeoffs or source selection. These problems are further compounded because the absence of accurate historical data makes it difficult to question the assumptions and construction of models since there is only limited ability to compare the forecasted costs of the models with actual data. Ideally, a model should be judged by its ability to predict the *known* costs of a similar system in service. This does not currently occur [Ref. 4].

## F. THE STATUS AND FUTURE OF LIFE CYCLE COSTING IN THE U.S.

From the above discussion it would appear that there are many problems with life cycle costing in the U.S., and that these are inhibiting its effective use as a decision tool. Life cycle cost analysis does not occur in an environment that encourages concern for future costs and necessarily takes the results the analysis seriously into account. There are also major limitations to the accuracy of the data which calls in to question the basis of life cycle cost modeling and the results it produces. Successful life cycle cost analysis is a direct result of managements emphasis and interest in what it has to say about better solutions to a problem.

However, having said all of this, as is illustrated with the F/A 18 case in the appendix, there are some examples where life cycle cost has been applied to make successful decisions in major system acquisition programs. The F/A 18 is often held up as an example of the potential of the application of the life cycle cost concept. What is interesting and relevant in this case is that it is in the role of a design tool, rather than as an affordability tool, that life cycle cost has been most successfully used.

What then is the future of life cycle cost in the U.S.? The popularity and emphasis on life cycle cost has ebbed and flowed in the U.S. Department of Defense over the last 30 years. There was a flurry of interest in the mid 1970's, but this waned during the 1980's. There appears to be increasing interest again. The ebbs and flows are largely in inverse response to the changing political and financial emphasis on defense. In the mid 1970's after the U.S. withdrawal from Vietnam, the Defense budget became tighter, and their was emphasis on efficiency, and concern with the costs of operating the current capability. However, in the 1980's when defense again became political popular, higher levels of funding were available, and the future costs of operating the hardware acquired was of less concern. In the 1990's, with the Gramm-Rudman Act requiring a balanced Federal budget, the Department of Defense are going to have to cut $167 billion from its budget between 1990 and 1992 [Ref.45]. The reforms in the Soviet Union and Eastern Bloc, which have lessened world tensions, are also having a significant effect on the political priority of defense. In this environment the future consequences of present day decision are likely to be of increasing concern to the Defense decision makers. Life cycle cost as a means to measure these consequences, and as a basis on which to make decisions favorable to reduced resource use in the future, is likely to receive renewed emphasis. Ultimately, the improvements of Defense financial accounting systems being forced by Congress, should result in improved accuracy and credibility of life cycle cost estimates such that they will support the increased acceptance and use of the technique and concept of life cycle cost as a decision tool.

## G. CHAPTER SUMMARY

This chapter has placed life cycle cost into the context of its use in the U.S. Department of Defense by exploring the regulations that govern weapons system acquisition, design to cost, integrated logistic support, and source selection; and by looking at the major organizations within Defense and the Navy in particular who have an interest in life cycle cost as a decision making tool. While the regulations and organizations do give life cycle cost some attention, they are do not do so consistently, and in practice it is acquisition cost that is most often the major cost consideration in decision making. A variety of reasons have been identified as causes for this. Not the least of these is that institutionally, the emphasis is on the acquisition of new equipment, rather than the costs to operate and support it. This is promoted by an organization that functionally separates acquisition and through life support, and by a system that assesses a program manager on his ability to manage a program within acquisition cost and schedule, when to achieve life cycle cost savings may involve addition costs in R&D and production.

Institutionally, life cycle cost is largely the purview of *budgeteers*, and it is this view that has, for the most part, dominated life cycle cost in the U.S. But with the current state of the data, life cycle cost is least suited to this application. Life cycle cost has been most successfully applied as design and logistics support tool, where complete data is less important to decision making.

The VAMOSC system's major limitations for cost estimating are: its accuracy; that for ships it is still primarily platform oriented; and that it only captures direct costs. As such it is not a true cost accounting system that provides all the data necessary for decision making. However, with Congressional pressure being applied to the Department of Defense to develop accounting systems that will reflect the true costs of operating and support of the current capability, life cycle cost is likely to become more credible as a decision making tool. With the prospect of decreasing defense budgets there is also likely to be increased concern for the costs of operating and support of new acquisitions, in which case, life cycle cost will also receive renewed interest.

# IV. THE APPLICATION OF LIFE CYCLE COSTING TO THE AUSTRALIAN DEFENSE FORCES

This study has highlighted some of the issues and problems with life cycle cost as it is practiced in the U.S. In this chapter the conclusions from the examination of life cycle cost in the U.S. will be applied to discuss the broad issues in the application of life cycle cost analysis to the decision making of the Australian Defense Forces (ADF). It is not intended in this chapter to conduct a detailed examination of the decision making process in the ADF, discuss current ADF policies and procedures, nor provide an in depth step by step procedure to implement life cycle costing. Rather, this chapter will briefly identify some of the key issues, and clarifying some misconceptions with the application of life cycle costing to Australia. The purpose of this chapter is to allow the ADF to benefit from the U.S. experience in using of life cycle costing for almost 30 years.

## A. BACKGROUND

While life cycle cost is not a totally new concept to the ADF, it has been rarely practiced. This does not mean that decisions in acquisition favorable to reduced life cycle cost have not been made. Rather, in most cases decisions have been made without the quantification of their life cycle cost impact. The consideration of cost in acquisition decisions usually concerns only acquisition cost. The directive by the Chief of Defense Force Staff, referred to in the introduction to this study, that life cycle cost be used "in the decision making process associated with the acquisition of equipments and weapon systems," is intended to formalize the consideration of life cycle cost rather than simply acquisition cost in acquisition decisions.

## B. THE AUSTRALIAN ACQUISITION ENVIRONMENT

The Australian acquisition process is similar to the U.S. process described in Chapter III. Its starting point is the identification of a need in the Defence Force Capabilities Guidelines Paper, which is then translated to a Capability Proposal by the Service's. Subject to endorsement, a program will be approved and progress through milestones in a similar manner to the process described for U.S. major system acquisitions.

A significant difference in the approach to acquisition between Australia and the U.S. however is that, for the most part, the Concept Demonstration/Validation and Full Scale Development Phases are usually passed over. As a nation with a comparatively small defense force, Australia commonly buys an existing design of military equipment which is already in an advanced stage of development or in actual production. Depending on the program, this may be a complete system or a platform upon which other existing systems are integrated. There are however exceptions to this. The Mulloka sonar and Minehunting catamaran for example, were fully developed in Australia.

In the 1970's and early 1980's major systems acquisition was characterized by the purchase of complete platforms from the U.S. Government under Foreign Military Sales agreements. Recently there has been a shift away from Foreign Military Sales to direct commercial procurement from the U.S. and other Western world countries. This is particularly true of the Navy, where currently the two highest profile Navy programs are the New Submarine and

ANZAC Frigate projects, which are of European commercial design. Increasingly, the selected systems will be co-produced in Australia.

## C. THE USES FOR LIFE CYCLE COST IN AUSTRALIA

As a nation with a comparatively small defense force Australia also usually procures only small quantities of hardware for its military acquisitions. Because of this, when an existing design is sought, there is only a limited ability for Australia to influence the design in favour of reduced life cycle costs. There is however, considerable scope to select amongst competing existing designs on the basis of life cycle cost. In those few instances that the designs are commissioned by the ADF, there is also the capability to set design to life cycle cost goals and thresholds, and to conduct trade studies on the basis of life cycle cost criteria. Thus, although the environment and scale may be slightly different than the U.S., the potential uses of life cycle cost are essentially the same. To repeat these, life cycle costs uses are for:

- affordability,
- source Selection and evaluation,
- logistics support analysis, and to a lesser extent
- detailed design.

## D. ORGANIZATIONAL ISSUES

Although there are exceptions such as with the F/A 18, the U.S. has, on the whole, had only limited success with the use of life cycle cost. It is however, still acknowledged that life cycle cost is a fundamentally better approach to making decisions during acquisition than acquisition cost alone. This study has highlighted that institutional problems and a lack of credibility are some of the principle reasons for the problems experienced with the application of life cycle cost in the U.S. Part of the problem in the U.S. has been overcoming the institutional inertia that in practice puts the acquisition of new equipment ahead of the costs to operate and support it. Change, particularly changes in institutional attitudes is a difficult thing to accomplish. As Franklin Roosevelt commented about the U.S. Navy:

> To change anything in the Na-a-vy is like punching a feather bed. You punch it with your right and you punch it with your left until you are finally exhausted, and then you find the damn bed just as it was before you started. [Ref. 46:p. 320]

If Australia is to avoid the futility of punching a feather bed, then there needs to a fundamental shift in attitudes to accord decisions favorable to reducing the costs of operation and support real management priority.

Some of the reasons why in the U.S. life cycle cost is not given real emphasis in acquisition decisions are partly moderated in the case of Australia. As a result of recent reorganizations in the Defense Department, the Supply, Engineering and Materiel Divisions have been amalgamated in each of the Services. Thus, the acquisition and operating and support functions are not as separated as they once were. However the project manager is still judged on meeting acquisition costs and staying on schedule, and the budgeting and political process in Australia, like the U.S., places considerably more emphasis on the funds to be spent in the near term rather than the long term. In this situation there needs to be higher level management realization of what life cycle cost is intended to achieve, and emphasis on it. In this authors opinion, the U.S. have largely only *paid lip service* to life cycle cost. Therefore while the regulations exist that say life cycle cost should be used, this is not followed in practice. This needs to be avoided in Australia if the ADF are to make full use of the potential of a life cycle cost management approach.

In the U.S. life cycle cost suffers because the predominance of the *budgeteers* view of life cycle cost for affordability. Yet, as discussed, this is a very limited use for life cycle cost analysis, and one which the current state of data in the U.S. does not readily support. It is unlikely that Australia will find it any more useful than the U.S. has, except to compare on a broad scale of affordability, very different approaches to meet a mission need. Therefore institutionally what needs to be emphasized are the other, more valuable uses for life cycle cost analysis.

To achieve this, life cycle cost should not become the purview of budgeteers alone. Rather the logistics and design directorates need to have specific responsibilities for life cycle cost in the acquisition process, and the institutional support to ensure it is considered. Organizationally, it is probably more appropriate that one of these areas be responsible for life cycle cost in each of the services, since it is in these areas that the most benefits will occur from the use of a life cycle cost approach.

## E. DATA

For life cycle cost to be accorded management attention it needs to be a credible decision making tool. The principle determinant of this is the accuracy and availability of the data. As discussed in Chapter II, data for life cycle cost analysis is fundamentally of three types: resource data, the physical and performance characteristics of the system being analyzed, and program data on utilization and deployment. Since Australia's systems are usually acquired in an advanced stage of development or production, the physical and performance parameters of the system are commonly known. While these figures may only be estimates, there are contractual mechanisms that can be used to ensure that the contractor's estimates are reasonable. Like the U.S., the largest single difficulty that Australia is likely to face in trying to establish life cycle cost, is in capturing the resource data for the operating and support costs of current systems to be used in the analysis.

It is the resource costs associated with the user's environment which are the most difficult because of the problems of capturing all relevant direct costs, and allocating indirect costs. The problems the U.S. are experiencing with this, and the shortfalls in current U.S. data collection systems have been discussed in detail. However, because the U.S. are having difficulty with data collection is no excuse to write off life cycle cost for Australia. The job of capturing and allocating cost is fundamentally easier in Australia because of the comparatively smaller scale of Australia's operations. There are fewer classes of weapons systems, fewer repair facilities, and therefore fewer common costs. To develop an accounting system that can provide accurate and complete data for life cycle cost purposes is not insurmountable. In commercial enterprise, where the capturing of cost is essential to pricing decisions, successful accounting systems have been developed at reasonable cost. A further point to consider is that without an accurate accounting system fully informed decisions, whether they be for life cycle cost analysis or any other purpose, cannot be made. Thus, a desirable effect of developing an accounting system for the purpose of life cycle cost is its potential for use in other management decisions.

There have been some suggestions that, at least initially, Australia could obtain U.S. data, under Foreign Military Sales or other arrangements, for life cycle cost analysis purposes. This however, would be of limited value particularly for the elements of operation and support costs even for common systems. Because of the often very different maintenance and operating environments between the two countries, costs are likely to be considerably different. For example, it can not be assumed that because it cost a certain amount to repair a component in the U.S., that it will cost the same amount if it is repaired in Australia. A possible approach to reflect the differences between the operating and support environments of Australia and the U.S., is to apply a scaling factor to the data. However, this approach will still only give data of limited accuracy because of the problem of determining what the scaling factor should be. Without knowledge of the real costs of operation and support in the Australian environment an appropriate scaling factor will be impossible to accurately determine. Also, because Australia is increasingly looking beyond the U.S. for weapons system purchases, common systems are not always going to be available.

As the discussion of life cycle cost in the U.S. has shown, the absence of accurate data upon which to base life cycle cost analysis is a major stumbling block to the credibility of the analysis. Without credibility, management are less likely to make decisions based on the analysis. This is particularly so when there are other institutional and cultural factors which continue to accord acquisition cost and schedule priority over the life cycle cost of a weapon system. Thus in many respects the cornerstone of life cycle cost analysis is accurate data.

## F. LIFE CYCLE COST MODELS AND METHODOLOGY

As was discussed in Chapter II there are a plethora of life cycle cost models available in the U.S. alone. When to these are added the many more that are available from other countries, the choice is next to endless. Out of all these models, Australia can not expect to find one *ideal* life cycle cost model that will fulfill all life cycle cost analysis needs. The diversity of use and application of life cycle cost analysis is reflected in the diversity of models. As was pointed out by the Director of the U.S. Air Force Working Group's study of available life cycle cost models:

> Some have suggested that one or a small number of ideal life cycle cost model developed by a select group of specialists would provide the analysis methods needed to address most or all Air Force life cycle cost problems. However, quite the reverse is true. [Ref. 22:p. 1]

The selection of a model or models will largely depend on what the purpose of the analysis is, and at what stage in the life cycle the analysis is conducted. Any model to be selected should be simple enough to be understood, and easily implemented, yet allow for sufficient detail to reasonably model the problem it is being used to solve. A note of caution on a fundamental principle of modeling is that the model should be selected to reflect the problem, not the problem framed in terms that will suit the available model.

As an approach to life cycle costing methodology, Australia is likely to find the life support cost approach to life cycle costing discussed in Chapter II, rather than a total life cycle cost approach to analysis, holds most potential use. This approach knows the acquisition cost and therefore focuses on the cost impact of the design on the logistics elements. The Swedish defense forces have also been using the life support cost approach to life cycle cost for source selection and logistics tradeoffs for many years with success. While to go into this in depth is outside the scope of this study, the reader is referred to an excellent example of the Swedish application of life cycle cost in a paper, *LCC Case Study of A Major Ground Radar System*, by Kargaard and Waak. [Ref. 47]

## G. LIFE CYCLE COSTING MANAGEMENT

Paramount to the successful management of life cycle costing is the clear understanding that life cycle cost is to be a major consideration in acquisition decisions. This has to be communicated to Defense management and to outside contractors who are tendering their system for Defense acquisition.

Porter has suggested that one way to ensure that the Program Manager considers life cycle cost is for the mandatory inclusion of a life cycle cost management plan in the acquisition strategy [Ref. 48:p. 87]. Thus, forcing the Program Manager to give early consideration to life cycle cost, and the way life cycle cost analysis will be conducted. However, this does not abrogate the need for higher management commitment and support for what life cycle cost is intended to achieve, nor to ensure that it occurs.

One way to ensure that contractors understand the importance of life cycle cost is by having life cycle cost requirements included in all Requests for Proposal (RFP). This requires a clear statement that life cycle cost will be a high priority source selection criteria. Butler and Neeches have suggested the following as an example of the wording that might be included in the RFP to convey this:

> Life-cycle cost is considered to be the greatest concern in the procurement. Proposed designs will not be considered solely on the basis of their acquisition cost, but also on the likelihood that they will exhibit low operation and support cost. It is the Government's intention to procure a design which economizes on all resources, both current and future. To this end, minimization of the cost of individual resources (e.g., manpower or support and test equipment) is deemed unacceptable: instead the designer shall accept responsibility for minimization of total life cycle cost. This requirement shall be considered satisfied by the integration of life cycle cost analysis in the design process. Appended to this solicitation are all materials required to carry out such analysis, as part of the design process. While bidders are not required to use these materials, they should recognize that the government intends to use them in the source selection process and that the requirement for their use shall be included in any contract which may arise from this solicitation. [Ref. 48:p. 89]

However, even specifying in the RFP the importance of life cyc'e cost may not necessarily achieve the desired response. In the paper, *LCC Case Study of A Major Ground Radar System,* [Ref. 47] cited above, the Swedes found with their procurement of the S-3D ground radar, it was beneficial to establish several rounds of the RFP process. In this approach, they fed back to the respondents information on where their original responses were deficient from a life cycle cost point of view. There was then an opportunity to respond a second time. The success of this method is evident when it is realized that ITT Gilfillan who by their own admission were possibly the worst contender from a life cycle cost point of view in the first round, won the contract on the basis of life cycle cost on their second attempt.

From the perspective of source selection, there are two possible approaches to selecting a system on the basis of life cycle cost. The first is to have the contractors conduct their own estimates using a specified model, with resource data provided by the government. The other approach is for the competing contractors to provide the physical and performance data for their system, to enable the program manager to conduct the analysis. This latter approach is, for example, the way the Swedish approached the S-3D radar acquisition cited above. Because of the often different definitions of cost elements in the various models, it is important in source selection that the same model be used in the comparison, and that the workings of the model be understood by all those that are making decisions based on its results.

A problem with either approach from the government's stand point is ensuring that the life cycle cost estimates, or the physical and performance characteristics, are realistic and going to be achieved. Warranties, reliability and maintainability guarantees, and incentive and award fee contracts are methods of ensuring this. An important point in the application of these methods, is that in the case of award fee contracts the government needs to be prepared to provide substantial awards for achieving life cycle cost goals, but also to withhold the award against contractor pressure, if the agreed upon goals are not met. Similarly, the government needs to be prepared to go to court if necessary to uphold warranty, guarantee and incentive provisions. There is no point in giving teeth to life cycle cost goals in acquisition if the teeth are not used when necessary. There have been occasions when Australia has been reluctant to use its *teeth* when contractors have failed to fulfill obligations in the past.

In summary, successful life cycle cost management requires a clear understanding that life cycle cost is to be a major determinant of the program. In the case of contractors, the importance of life cycle cost needs to be spelt out in the RFP. To ensure accurate instead of optimistic estimates, contractual provisions need to be implemented, and there needs to be the will to back them up when necessary.

## H. CHAPTER CONCLUSIONS

This chapter has brought together some of the key findings from the study of life cycle cost in the U.S., to discuss some major points with the application of life cycle cost in the Australian Defense Forces. These major points can be summarized as

- For Australia, life cycle cost is likely to be most successful if it is used as a tool for source selection and logistics analysis rather than for budgetary purposes. In these roles a life support cost rather than a total life cycle cost approach to analysis is appropriate.
- For life cycle cost to be successful, the ADF needs to shift attitudes at all levels to accord decisions favorable to reducing the costs of operation and support management priority.
- Within each of the Services one organization, probably logistics or design related, needs to be made responsible for life cycle cost, and become its advocate.
- Australia needs to develop an accurate accounting system that can be used for life cycle cost analysis, as well as other management decisions.
- The ADF cannot expect to find one *ideal* life cycle cost model. Instead different models will be required for different purposes.
- The importance of life cycle cost in source selection needs to be communicated to competing contractors. The vehicle for this is the RFP.
- Contractual provisions which the government are prepared to back up when necessary are essential to ensure realistic life cycle cost estimates.

If the path to life cycle cost analysis seems distant and difficult for the ADF, it should be remembered that better acquisition decisions are likely to be made considering life cycle cost than without. Starting from the beginning, and being able to benefit from the experience of others means that fewer mistakes are likely to be made if the lessons learnt from others are understood and applied.

# V. ANSWERS TO RESEARCH QUESTIONS, RECOMMENDATIONS AND AREAS FOR FURTHER RESEARCH

## A. ANSWERS TO RESEARCH QUESTIONS

This study set out with two principle purposes—to examine and reach conclusions on life cycle costing in the U.S., and to apply these conclusions to the major issues with implementing life cycle cost analysis in the acquisition decisions of the Australia Defense Forces. In concert with this, two subsidiary and a primary research question were posed. The answers to these questions follow.

### 1. What Are The Principle Characteristics of Life Cycle Cost Analysis Approach to Decision Making?

This study has identified, in chapter II, a general analysis approach for life cycle costing. In the course of this study it has been stressed that life cycle cost is a decision tool that considers the future consequences of present day decisions. In this respect life cycle cost is both a concept and a technique. As a concept it is aimed at reduced costs of ownership over the life cycle of a system. As a technique it provides an analysis approach to quantify these costs over the life cycle for the purpose of decision making.

Life cycle cost concerns the tradeoffs of reliability, maintainability, and supportability—the operating and support cost drivers, with any increases in R&D and production costs that may result. In this life cycle cost analysis should be thought of in the larger sense as cost effectiveness analysis.

### 2. How and with what Success is Life Cycle Costing Used in the U.S. Department of Defense, and what Criticisms are there of it?

It has been concluded that life cycle cost has had only limited success in the U.S. Many of the problems with the application of life cycle cost in the U.S. stem from a lack of credibility. There is not real management emphasis on the concept of life cycle cost. Although life cycle cost is given some attention in the regulations that govern the acquisition of weapons systems, in practice there is not institutional concern for the future consequences of present day decisions. In the situation where acquisition and operation and support are functionally separated, the institutional emphasis is on the acquisition of new more capable systems within acquisition cost and schedule, rather than on the costs to operate and maintain them. If life cycle cost analysis is done by program offices at all, it is usually only as a tick in the box on the way through the approval process rather than as the basis upon which any real decisions of consequence are made. The F/A 18 program studied in the appendix is the exception, that shows the potential of a life cycle cost approach

Attention to life cycle cost is dissipated in the U.S. because it is the *budgeteers* view of life cycle cost as a technique for affordability that dominates. Yet, it is in this area that life cycle cost has been least successful, and for which it is least suited. Life cycle cost is most applicable as the criteria to evaluate and tradeoff logistics and design issues.

The cornerstone of successful life cycle cost analysis is the data. But the current data system for operation and support costs in the U.S.—the VAMOSC system, is of limited accuracy. VAMOSC does not capture all costs associated with a weapons system. The inadequacy of the Department of Defense's accounting systems have recently been the subject of considerable congressional and GAO attention, and it is likely that renewed efforts to capture and report costs will result in more accurate data, and as a consequence, better life cycle cost estimates in the future.

### 3. What are the Essential Issues to Consider in the Application of Life Cycle Costing to the Decision Making of the Australian Defense Forces?

Australia will get most use from a life cycle cost approach to acquisition if it is used in source selection of competing systems and in logistics tradeoffs. For this a life support cost approach to life cycle costing is appropriate, and will simplify the analysis. There is only limited use of the technique for affordability issues. However, to achieve the full benefit from life cycle costing requires more than just writing it into the regulations. There needs to be the acceptance at all levels of the concept of life cycle cost, and what it is trying to do for decisions of consequence to be made on the basis of life cycle cost analysis. The key to life cycle cost analysis is the data, and Australia needs to develop an accounting system that reflects the costs of operation and support for Australia. This is not insurmountable, and is fundamentally easier than in the U.S. It will also be valuable for other decision making purposes.

The major point in Australia's case is that better acquisition decisions are likely to made with the consideration of life cycle cost than without. Being able to benefit from the U.S. experience of life cycle cost, Australia has the opportunity to implement life cycle costing into the decision making of the

Australian Defense Forces without many of the problems that have been experienced in the U.S. over the 30 years that life cycle cost has been in use.

## B. RECOMMENDATIONS

The recommendations from this study concern some key points to be considered in the application of life cycle costing to the decision making of the Australian Defense Forces. These were listed in the conclusions to Chapter IV. They are repeated here for consistency.

- For Australia, life cycle cost is likely to be most successful if it is used as a tool for source selection and logistics analysis rather than for budgetary purposes. In these roles a life support cost rather than a total life cycle cost approach to analysis is appropriate.
- For life cycle cost to be successful, the ADF needs to shift attitudes at all levels to accord decisions favorable to reducing the costs of operation and support management priority.
- Within each of the Services one organization, probably logistics or design related, needs to be made responsible for life cycle cost, and become its advocate.
- Australia needs to develop an accurate accounting system that can be used for life cycle cost analysis, as well as other management decisions.
- The ADF cannot expect to find one *ideal* life cycle cost model. Instead different models will be required for different purposes.
- The importance of life cycle cost in source selection needs to be communicated to competing contractors. The vehicle for this is the RFP.
- Contractual provisions which the government are prepared to back up when necessary are essential to ensure realistic life cycle cost estimates.

## C. AREAS FOR FURTHER RESEARCH

In the course of researching this study several areas for further research have been identified. These include:

- An analysis and comparison of major life cycle cost models, both commercial and government, in order to update the studies done in the 1970s in this area.

- A review of current accounting systems in the Australian Defense Forces with a view to incorporating and adding to them to provide a consolidated operating and support data base for life cycle cost and other decisions making purposes.
- A comparison of the methodology and practice of life cycle cost analysis in the U.S. with its practice in other countries.

# APPENDIX A. CASE STUDIES OF THE APPLICATION OF LIFE CYCLE COST

## A. THE APPLICATION OF LIFE CYCLE COST IN THE THE SSN 21 SUBMARINE PROGRAM[1]

### 1. Introduction

The SSN 21 SEAWOLF nuclear attack submarine is intended to counter the U.S. Navy's perceived Soviet submarine threat in the early 21st century. With a submerged displacement of 9150 tons it will not only be larger than current USN classes of submarines, the SSN637 STURGEON, and SSN688 LOS ANGELES classes, but is also intended to be faster, quieter, more heavily armed, and available for greater lengths of time without significant maintenance. The program has recently been given DAB approval to commence production. The lead ship is planned for delivery in 1994, and procurement of a further 28 submarines is planned. The acquisition strategy of the program is for two shipyards to be in competition throughout the development phases of the program, with one being selected for the lead ship and follow-on contracts. Both shipyards have been involved in aspects of the design through these phases of the program.

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[1] This case study was compiled from PMS 350's *The Seawolf CAIG Presentation*, 6 May 1988 [Ref. 49]; and, a personal interview with Mr F. Ambross of PMS 350 [Ref. 50] All diagrams have been extracted from these sources.

### 2. Program Objectives and Cost Drivers

From the perspective of life cycle cost, two objectives of the program are that firstly, the SEAWOLF be available for more operating time during its life cycle than current USN nuclear submarines; and secondly, that it will cost comparatively less to operate and support. The major ways these objectives will be met are by designing for a Submarine Extended Operating Cycle (SEOC) whereby there will be greater periods of operating time between depot availabilities. This has already been done with some of the LOS ANGELES class where a modified SEOC called ESEOC has been used. The effects of this for the SEAWOLF in comparison to other submarines is illustrated at Figure 12. From this figure it can be seen that for the SEAWOLF the only major depot overhaul is for refueling, where as for the worst case pre SEOC submarines there are five or possibly six depot overhauls in the same period. (The last of these may not be held depending on when the ships will be decommissioned.) The SEAWOLF is still planned to have eight lesser Selected Repair Availabilities (SRAs) during its life cycle like both the normal (SEOC) and modified SEOC (ESEOC) LOS ANGELES class. Additionally, to help allow a SEOC to be used, a major initiative has been designing the SEAWOLF for greater accessibility. This has resulted in larger five foot logistic access hatches, and *flow paths* being incorporated in the design to enable equipment to be removed without the ship having to enter dock.

Experience with the LOS ANGELES submarines indicated that depot availability was one of the major costs for operating and support in

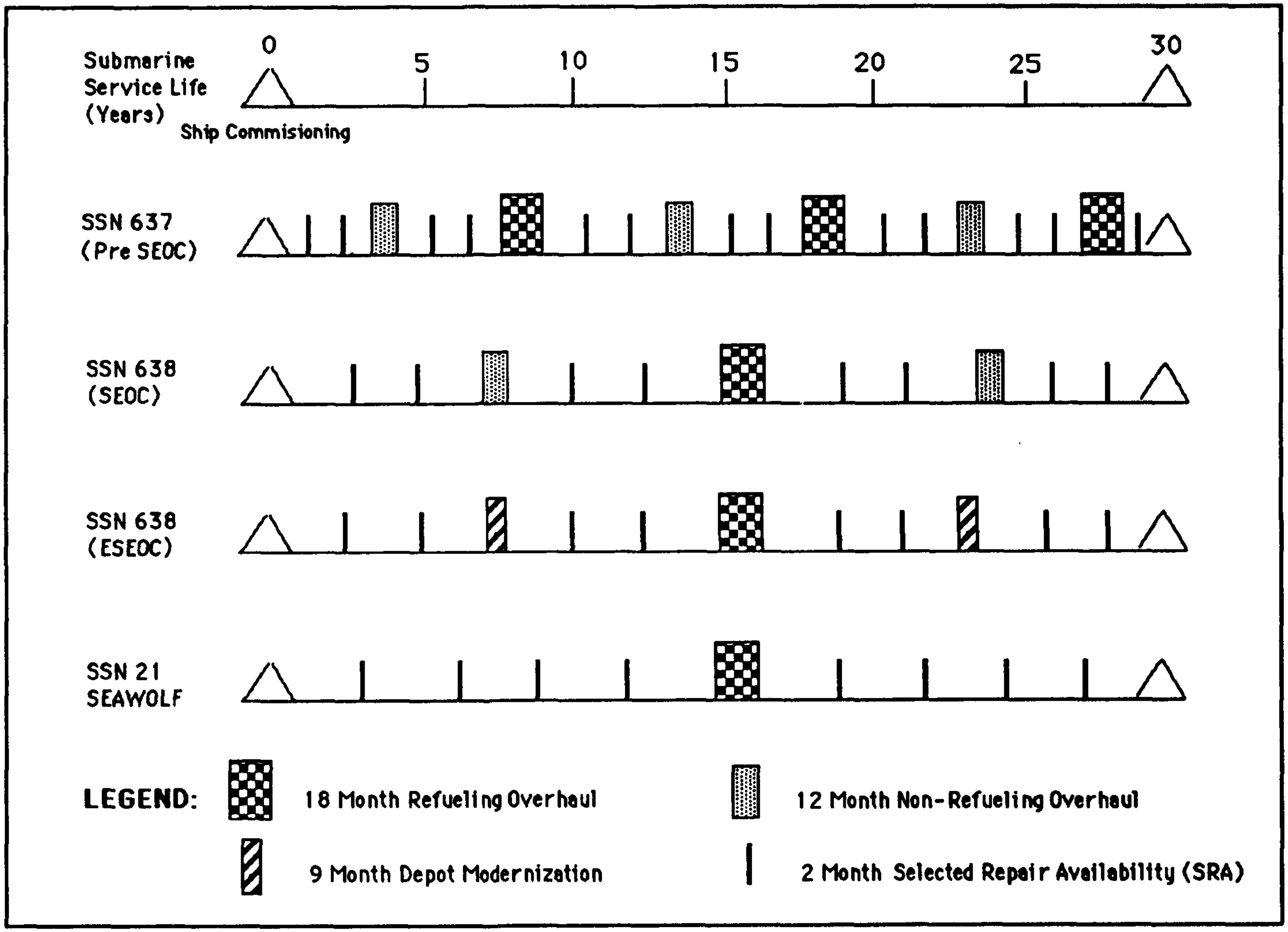

Figure 12. Submarine Planned Availabilities

submarines. It was also realized that during an availability a considerable portion of the time was spent in making cuts in the pressure hull to gain access to allow for removal of equipment. It is estimated that over a 30 year life cycle, the design initiatives in these areas for the SEAWOLF will gain two years operating time and save $25 million in operating and support costs compared to the LOS ANGELES class submarines, and result in an improvement of five years operating time and save $300 million over the older STURGEON class submarines. It must be said however, that while the dollar savings estimated resulted from a formal life cycle cost analysis, the design decisions did not. Discussion with the program office indicated that while the designers were aware of the program objectives, the design decisions were reached based on the experience with the LOS ANGELES class where, after some changes to the maintenance concept, the modified SEOC concept was already in place.

### 3. Overview of Cost Estimating Methodology

Life Cycle cost estimates were developed by the program for the purposes of CAIG review. The O&S cost estimates will be examined in some detail. The following is an overview to the estimating methodology for the Research, Development, Test and Evaluation (RDT&E) and Procurement estimates. The RDT&E estimate's methodology was a combination of engineering and analogy with other programs. The procurement estimate methodology was a combination of parametric and analogy techniques. Data was obtained from shipbuilder's return cost data for other programs with a factoring applied to reflect anticipated labor market conditions. The data was applied to learning curves experienced with the TRIDENT program which utilized similar modular construction. To the estimates developed in this way was also added known material costs for Government Furnished Equipment (GFE), and initial outfitting for repair parts, equipage and consumables, and other non recurring ILS costs. Existing cost estimating relationships developed in NAVSEA were used where appropriate.

### 4. O&S Cost Estimates

The operating and support costs estimated were the recurring costs required to man, operate, maintain and support the submarine. The non recurring costs were included by the program in the procurement estimates. The drivers to operating and support costs were determined to be the displacement of the submarine, the crew size, and the depot overhaul maintenance cycle of one refueling overhaul of 18 months duration, and 8 lesser availabilities of 2 months each over a 30 year service life.

The principle source of data for the estimate was VAMOSC- Ships. Costs were broken down and categorized in accordance with the categories recorded in VAMOSC, and CAIG guidance. Because VAMOSC does not include indirect costs, these had to be factored from the Navy Resource Cost Model (NARM). VAMOSC data was also found to be inadequate for depot overhaul, SRA, and intermediate maintenance costs. Actual source data was obtained for these. The recurring costs for the BSY-2 Combat System were based on the estimates developed by PMS418, the program responsible for it.

On the basis of the data, cost estimating relationships were developed using multi variate regression analysis. The O&S cost estimates by category are at Table 3. As a point of comparison, cost estimates were produced for all components of life cycle cost for the LOS ANGELES AND STURGEON classes of submarine using the CERs developed for the SEAWOLF. The program conducted sensitivity and uncertainty analysis on their estimates, although the uncertainty analysis is reported as a series of statements rather than statistical uncertainty.

TABLE 3. SEAWOLF O&S ANNUAL COST ESTIMATE—ALL CATEGORIES

| MILLIONS OF FY 1985 DOLLARS | |
|---|---|
| 1.0 Direct Unit Cost | $5.071 |
| 1.1 Personnel | (3.094) |
| 1.2 Maintenance | (1.827) |
| 1.3 Purchased Services | (0.150) |
| 2.0 Submarine IMA Costs | $2.361 |
| 3.0 Submarine Depot Costs | $13.064 |
| 3.1 Overhauls | (4.224) |
| 3.2 SRAs | (2.393) |
| 3.3 Non-Scheduled Repairs | (0.830) |
| 3.4 Fleet Modernization | (3.773) |
| 3.5 Other Depot | (1.375) |
| 3.6 Inactivation | (0.469) |
| 4.0 Indirect Costs | $ 5.326 |
| 4.1 Training | (0.350) |
| 4.2 VAMOSC Indirect | (0.074) |
| 4.3 Non VAMOSC Indirect | (4.902) |
| BSY-2 Combat System | $ 5.334 |
| Support Personnel | (0.075) |
| Recurring procurement | (1.926) |
| Operation & Maintenance | (3.333) |
| Total Annual SEAWOLF O&S Costs | $31.156 |

### 5. Analysis

The life cycle cost analysis described here was done for the sole purpose of CAIG review. As such, its purpose was to address affordability decisions rather than design or support tradeoffs. These other uses for life cycle cost analysis had neither been done, nor were they contemplated. From the programs perspective, the purpose of life cycle cost analysis was to get the program through milestone reviews by showing higher authority that they were getting a larger more capable weapon system at less cost than current capability. The estimating methodology was statistical cost estimating relationships at a gross level. A bottom up estimate that might better reflect the characteristics of the design was not intended.

It is interesting to note that although supportability considerations were of obvious importance in design, the design decisions were made without reference to life cycle cost. There is little doubt that a design which can increase maintainability by providing improved access, and reduce overhaul frequency is going to result in reduced operating and support costs. For these reasons it was felt by the people spoken to at the program office that there would have been little benefit in using life cycle cost in the design stage. Additionally, many of the larger design requirements were mandated, and the program had little discretion over them. The mandated requirements were things like, to meet the mission need the design had to be a submarine, it had to be nuclear powered, and it could have a crew of no more than 134, there were also significant amounts of GFE which would be furnished and which the design had to accommodate. However, as will be discussed in the next case on the F/A 18, there are many issues of detailed design and equipment selection that if made on the basis of life cycle cost can result in significant cost savings over the life cycle. These opportunities were missed with the SSN-21.

Life cycle cost for logistics tradeoffs was not being done by the program office or functional areas. One reason was that the program did not have confidence in the NAVSEA Level of Repair Analysis (LORA) model. It was, in their opinion, cumbersome and complicated, and required too many data inputs. Rather, level of repair was being done on the basis of purely *technical factors*.

A major issue that was brought out, is that the VAMOSC data was neither complete nor totally accurate. Discussions with program personnel indicated that there were many occasions when the VAMOSC data just did not seem to reflect what the estimators considered to be the real costs. This was particularly so for intermediate maintenance which appeared in VAMOSC to be understated by some seven times when compared to actual workload documents. The program office were also unable to develop a detailed CER for non-scheduled repair on the basis of the VAMOSC data. They ended up resorting to a simple averaging of the yearly costs for non-scheduled repair of the other submarines.

### 6. Case Conclusion

The purpose of this case study of the SEAWOLF submarine program is to illustrate some of the issues and problems in a real life cycle cost estimating procedure. As discussed in the body of this study, this case study is indicative of many of the issues and problems and attitudes of life cycle cost in the U.S.

## B. THE F/A 18 HORNET AIRCRAFT

### 1. Introduction

The F/A 18 HORNET is the U.S. Navy's replacement for F-4 and A-7 aircraft in the fighter escort and light attack roles respectively. 1366 aircraft are being procured by the U.S. Navy and Marines, and several hundred by the military forces of other countries, including 75 by the Royal Australian Air Force. With the F/A 18, the U.S. Navy took what it termed a "New Look" to acquisition. Concerned about the low in-commission rates of carrier based aircraft, the high manning levels that were required to support them [Ref. 51:p. 15], and the increasing costs for their operation and support, the Navy initiated with the F/A 18 program a life cycle cost management approach to its acquisition. There are several characteristics that differentiate the approach of the F/A 18 program. These are:

- The establishment of design to life cycle cost goals and thresholds that were firmly contractually binding.
- The provision of funding for reliability and maintainability improvements during design.
- The use of award fee contracting provisions to incentive the prime contractor—McDonnell Douglas Aircraft Company, to achieve the program's life cycle cost, and reliability and maintainability goals.

This brief case study will review the major aspects of the of this management approach to the F/A 18 acquisition, and examine the life cycle costing methodology that was used. In so doing it is intended to illustrate the essential aspects of a successful life cycle costing approach as an adjunct to the rest of this study.

### 2. Program Objectives and Life Cycle Cost Goals

The overall objectives of the program office were to produce a more capable aircraft that offered significant improvements in life cycle cost over current capability. The program office developed a life cycle cost baseline and threshold for the F/A 18, and translated this into maintainability and reliability goals for the aircraft that were held to be at least as important as acquisition cost and schedule. The more significant of these goals were:

- A maintenance man-hours per flight hour of 18 hours,
- An engine replacement time of 21 minutes with a crew of four,
- A radar replacement time of 20 minutes with a crew of two,
- A mean time to repair of 1.78 hours,
- A turnaround time of 15 minutes,
- A mean time between maintenance of 0.49 flight hours, and
- An operational readiness rate (inherent availability) of 85 percent. [Ref. 52:p. 3]

### 3. Life Cycle Cost Management

Integral to the management of the F/A 18 program was a close relationship with McDonnell Douglas Aircraft Company. McDonnell were brought on board to the concept of designing for reduced life cycle cost by the provision of award fees in the contract. An award fee, unlike a plain incentive provision in a contract, is at the total discretion of the program manager to award. Program management, based on their own qualative criteria, may award the full amount, only some, or none of the available award. A total award fee of $39 million was available for life cycle cost related areas in the F/A 18 program. Of this $39 million, $15 million was available for life cycle cost management, a further $12 million was available if the contractor could demonstrate that they exceeded the reliability goals of the design, and an additional $12 million if they exceeded the maintainability goals. The award payments were available at six monthly intervals from mid 1976 until 1980.

The $15 million life cycle cost management award was based on qualative evaluation of the contractors performance in the areas of life cycle cost reduction, control of subcontractors life cycle cost, meeting the design to cost goals, and achieving program milestones. [Ref. 53:p. 404] It is significant that the prime contractor was expected, and did, use part of its award fees to incentivize subcontractors to meet their own reliability, maintainability and life cycle cost goals.

To track McDonnell's performance, a schedule of testing and reporting was introduced. Amongst the various reports required were life cycle cost status reports. The life cycle cost status reports presented the current life cycle cost estimates in relation to the baseline, and an explanation of any variances. They also projected a life cycle cost trend in relation to what was achieved relative to the baseline. [Ref. 3:p. 408] Through the course of the program the baseline was changed on several occasions due to changes in the Navy's operational profile for the aircraft.

### 4. Development of the Program's Life Cycle Cost Estimates

Cost estimates were developed by the program office for two reasons: for the purpose of CAIG and DAB review, and as the cost baseline discussed above, on which the contractors performance relative to life cycle cost could be evaluated. As in the SSN-21 case, this case will concentrate on the operating and support cost estimating procedure.

Because for the F/A 18 the purpose of the cost estimates were more than just to get the program through the review process, the estimating methodology had *to reflect the unique design sensitive factors*. For this reason the program office approached the task of estimating operating and support cost in a different way than did the SSN-21 in the previous case study.

The program's estimating methodology used two models. Firstly, there was a top level accounting model that organized and categorized costs according to the cost element structure preferred by the CAIG and published in their cost estimating guidance. Feeding into this was a second model that the program termed a "factors model." For the top down estimating approach the factors model used statistically derived cost estimating relationships. For the bottom up approach the factors were arrived at by simple algorithms, but developed at a detailed level. In each case, the resulting factors were applied in the top level model to categorize the costs to the accepted cost element structure. The relationship between the models and the estimating techniques is illustrated in Figure 13. Whether the factors were derived from CERs or from the bottom up techniques, they were intended to reflect the design characteristics of the aircraft. The top down CERs were driven by design parameters such as reliability, maintainability, flyaway cost, and weight [Ref. 54:p. 27] The bottom up estimate, from the subsystem level, utilized cost data obtained from analogous systems and, and after appropriate scaling, applied it to repair frequency and maintainability estimates obtained from the contractor and through logistic support analysis (LSA). In general costs were developed on a cost per maintenance action basis, which was then adjusted by the maintenance actions per flight hour. [Ref. 54:p. 28] An example comparison of the CER and bottom up algorithm for component rework costs is at Figure 14. For the bottom up approach the algorithm is applied to each of the subsystems. The principle source of data for both the top down and bottom up estimates was VAMOSC-Air. The bottom up estimate utilized the

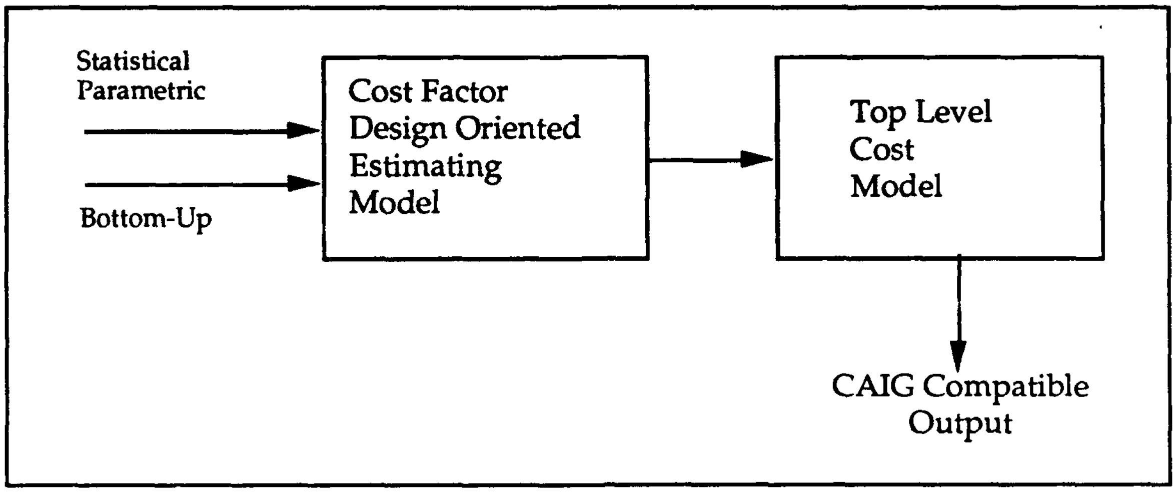

**Figure 13. The F/A 18 Costing Process [Ref. 54:p. 21]**

CER Model

Component Rework Cost = 105.673 + 31.918 {0.74 (AF) + (AV + PROP)}

Where:

AF = Air Frame Cost in millions of dollars

AV + PROP = Avionics System Cost + Propulsion System Cost in millions of dollars

EW = Empty Weight in thousands of pounds

MFHBH = Mean Flight Hours between Failure

Vmax = Aircraft Maximum Speed in knots

Bottom Up Model

Component Rework Cost Per Aircraft Per Year = $/FH x 360 FH/AC/yr

and $/FH = $ MA x MA/FH

Where:

FH = Flight Hours

MA = Maintenance Actions

- $/MA is derived from fleet data for analogous systems. The costs are normalized from 2, 4, and 5 digit data from VAMOSC.

**Figure 14. F/A 18 Component Rework Cost Factors Derivation [Ref. 54:p. 33]**

VAMOSC Maintenance Subsystem data available in VAMOSC-Air to the 5 digit work unit code level.

### 5. The Application of Life Cycle Cost Analysis to the Design

Life cycle cost analysis was not only used for program review and as one of the means to measure the improvements in reliability and maintainability, but it was itself the basis upon which design decisions were made by the contractor. Throughout the design of the F/A 18 some 700 trade studies using life cycle cost criteria were conducted. Some of the more significant of these were: the decision to not allow the wing pylon assembly to be jettisoned with the tanks and armament racks should it be necessary to jettison external stores, even though there was a weight and performance penalty; a flight control simplification study that resulted in significant cost and weight savings; and the decision to have a common wheel and tire fit across the fighter and attack configurations of the aircraft, even though to do so resulted in some performance degradation, but was estimated to save some $7.455 million per aircraft over the life cycle. [Ref. 53:p. 407] All in all, approximately two thirds of the F/A 18's subsystems were designed or redesigned on the basis of reliability, maintainability and life cycle cost criteria. [Ref. 55:p. 41]

### 6. The Success of the F/A 18's Life Cycle Cost Program

The application of a life cycle cost approach to the F/A 18 acquisition resulted in significant reliability and maintainability growth in the aircraft design. Compared to earlier aircraft the F/A 18 is demonstrating twice the reliability [Ref. 55:p. 43], and requires between 32 and 62 less squadron personnel for its operation and support than the capability it replaces

[Ref. 53:p. 408]. In comparison with the A-7 and F-4, savings in operation and support costs are estimated to be in the order of $3.981 billion over a 20 year life cycle [Ref. 53:p. 407]. For their efforts McDonnell Douglas received 68 percent of the $12 million award available for reliability, 94 percent of the $12 million for maintainability, and 51 percent of the $15 million for life cycle cost management. [Ref. 53:p. 408]

### 7. Case Conclusions

In the F/A 18 case, life cycle costing was applied as a concept and as a technique with great success. It was not just something that the program office did to get the required tick in the box on the way through the approval process. Rather, real decisions were made on the basis of life cycle cost. Decisions that might otherwise not have been made. This contrasts with the SSN-21 where life cycle cost estimation was largely done because it had to be for program approval. The F/A 18 program office approached the acquisition with life cycle cost as the primary consideration. In the trade studies, if significant life cycle cost savings could be achieved the opportunity was taken, even if it meant slight degradations in performance or weight penalties. In their estimating methodology the program office sought to have estimates that would truly reflect the design characteristics of the aircraft. This was probably a more difficult approach, but one that was necessary given the high priority of life cycle cost in design. In much of the general life cycle cost literature the F/A 18 program is held up as an example of the potential of life cycle cost in acquisition. This is justified given the success of the life cycle cost approach in this program.

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